ARCTIC

Journal of the Arctic Institute of North America

Vol. 11, No. 3 Published in Montreal, Quebec **1958**

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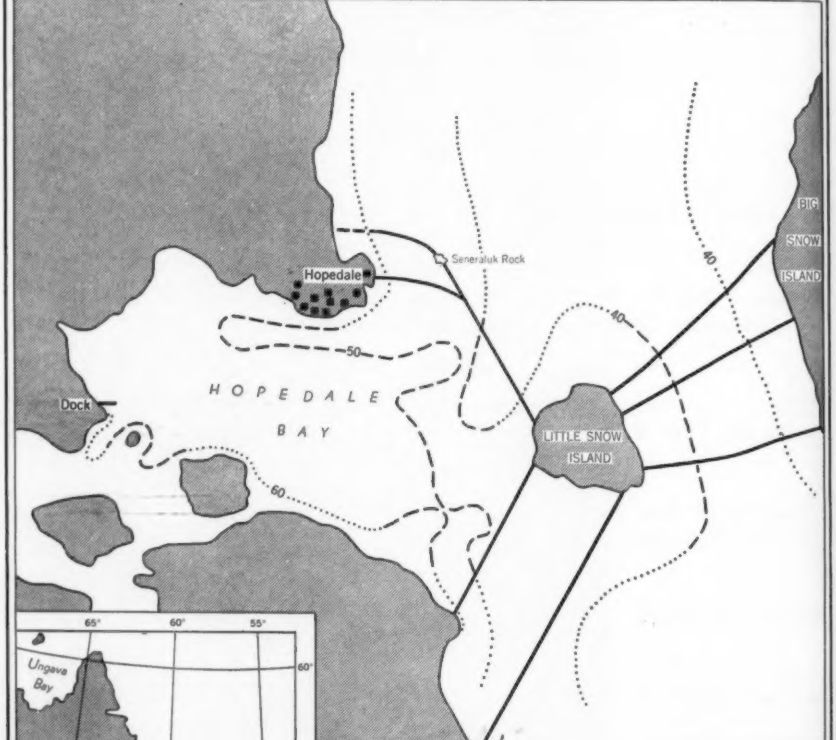

H.E. Mindak

Fig. 1. Map of the bay area: general areas of thermal cracking are represented by heavy black lines, contours show trends of ice thickness in centimetres on January 30, 1956, inset gives general location of Hopedale.

OBSERVATIONS ON THE PHYSICAL PROPERTIES OF SEA-ICE AT HOPEDALE, LABRADOR*†

Wilford F. Weeks and Owen S. Lee††**

Introduction

DURING the winter in the northern hemisphere alone over 16 million square kilometres of ocean surface are covered by ice. This is roughly an area twice the size of the United States or eight times the area covered by glaciers. Some efforts have been made to interpret drift patterns of sea-ice and their effect on the movement of ships and to develop methods of forecasting sea-ice formation and growth from known meteorological parameters. However, very little is known concerning the detailed behaviour and growth of this material (Armstrong, 1956).

During the last three winters the Air Force Cambridge Research Center, the Navy Hydrographic Office and the Snow, Ice, and Permafrost Research Establishment have sponsored a joint project to study the general physical properties of sea-ice by direct observations in the field. This paper reports some preliminary results obtained from data collected during the winter of 1955 to 1956 at Hopedale, Labrador.

Physical setting

Hopedale is a village on the Labrador coast approximately 125 miles north of Goose Bay. This location offers an opportunity to study the formation of sea-ice in a protected bay, which has a typical subarctic climate. The general configuration of the bay is shown in Fig. 1. It is protected from heavy wave action by a number of small islands that extend as far as 10 miles from the coast-line. The tides in the harbour are semi-diurnal and are approximately 2 metres in height. There are no appreciable currents in the harbour and, with one exception, no thin areas were noticed in the ice cover due to the action of tidal currents.

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* The statements in this paper represent the opinion of the authors and are not to be construed as an official release from the U.S. Navy Electronics Laboratory or the U.S. Navy Hydrographic Office.

† A portion of this paper was read at the Washington, D.C. meeting of the American Geophysical Union, May 2, 1957 (Weeks and Lee, 1957).

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The water of the bay, as any sea-water with a salinity greater than 24.7‰, has a freezing point higher than the temperature of maximum density. Surface cooling creates an unstable vertical density distribution, which causes convective mixing. This process transports the sensible heat, which is stored in the lower layers of the water, to the surface where it is dissipated. At the time of initial ice-formation the bay water is practically free of sensible heat and it remains isothermal at the freezing point during the winter. A relatively small amount of sensible heat becomes available as freezing releases salts to the underlying water and lowers the freezing point. The average salinity during the period of freezing is 32.7‰ and the average freezing point is −1.8°C.

Formation of the initial ice-cover

Initial ice-formation took place during slight to medium wave action. First small plate-like dendrites of pure ice were noted in the upper 10 cm. of the water near shore. These crystals were extremely fragile and variable in lateral dimensions. They were 0.5 cm. to 2.5 cm. wide and had a squarish or irregular outline. Their height varied from 0.1 mm. to 1 mm.

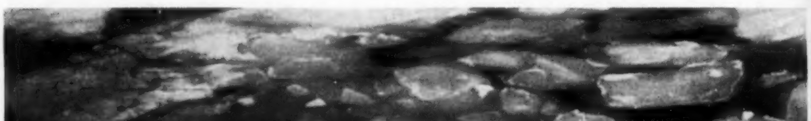

Fig. 2. Unconsolidated pancakes separated by frazil slush and clear water (the dark areas).

Fig. 3. Pancakes undergoing abrasion due to heavy wave motion.

The movement of the water caused these crystals to brush against each other and to disintegrate until a "mush" of crystal fragments formed. As freezing continued, this "mush" layer began to congeal into pancake-like bodies (Fig. 2), which continually changed in shape owing to abrasion from surrounding pancakes and slight wave motion. (Fig. 3). The diameters of the pancakes varied from 0.2 m. to 4.0 m. The appearance of the closely compacted pancakes was similar to a giant jigsaw puzzle. The general shape of the pancakes depended on their position with respect to wave motion and the shore. In the open ocean, where no fixed boundaries were present, the pancakes were usually circular in outline owing to constant abrasion by other pancakes, which tended to remove sharp corners. Close to shore the motion came from only one direction (the direction of open water) and the pancakes were commonly non-equidimensional with their long axes parallel to the shore-line. Fig. 4 shows a newly formed ice-sheet composed entirely of small pancakes cemented together by a mush of frazil-crystals.

During calm periods, usually at night, sheet-ice formed. Sheet-ice on a lake has been described by Wilson, Zumberge, and Marshall (1954) as "an ice-cover which presents a smooth unbroken surface on which there are no highly evident horizontal changes in the structure of the ice layer".

Fig. 4. Newly formed ice-sheet composed entirely of small pancakes cemented together by a mush of frazil crystals.

This definition is also applicable to sea-ice. Where surface waves are present the ice-cover that forms has an initial thickness of 8 cm. to 10 cm. In contrast, sheet-ice has an initial thickness of the order of a few millimetres. It usually starts to form at foreign objects or at the edge of an existing ice-sheet. From there it grows outward as a very thin film with a definite advancing front. After large sections of Hopedale Bay were covered with sheet-ice it also formed in holes where freezing was delayed and in areas where ice blocks had been removed for study (Fig. 5). After the initial ice-sheet had formed, sheet-ice developed beneath joined pancakes and slush-ice to form a composite ice-sheet (Fig. 6).

Sheet-ice is composed of vertically elongated crystals, which extend from a few millimetres below the top of the ice to the bottom. The crystal diameters vary from a fraction of a millimetre to 20 cm. The brine pockets and air bubbles occur in a series of parallel layers in the ice crystals. The average distance between the midpoints of two successive brine layers is approximately 0.45 mm. Sea-ice crystals below the upper 5 cm. of the ice-sheet are characterized by c-axes (Fig. 7) that always lie parallel to the water-surface. In marked contrast both vertical and horizontal c-axis orientations were observed in lake-ice at Hopedale (Fig. 8). Pronounced vertical c-axis orientations have commonly been observed in lake-ice (Wilson, Zumberge and Marshall, 1954). However, recent unpublished data indicate that

Fig. 5. Rectangular test pond cut in the ice-sheet that has frozen over with sheet-ice.

the horizontal c-axis orientations observed at the Hopedale lake are not uncommon (E. W. Marshall, personal communication).

A large number of thin sections and crystal impressions of sea-ice were made at Hopedale to determine (a) the distribution of brine and the method of its movement through the ice-sheet and (b) the reasons for the pronounced horizontal c-axis orientation. The results of this crystallographic study will be published later (Weeks, 1958).

Salinity of the initial ice-cover

The salinities presented here were determined by hydrometers that were calibrated directly in salinity. The samples were collected by drilling vertically into the ice with a 7.6-cm.-diameter ice-corer (Bader, 1957). The core was immediately cut into 7.6-cm. segments (3-cm segments for thin ice), placed in sealed containers, melted, and brought to a temperature of approximately 15°C. The water temperature and salinity were then measured and suitable temperature corrections were applied to give the salinity of the water sample at 15°C. Graphs of ice salinity versus depth in the ice-sheet gave curves without sharp discontinuities and irregularities.

Fig. 9 gives profiles of a series of successive salinity samples, which were taken between the dates December 23 and 29, 1955 from thin ice north of

Fig. 6. Composite ice-sheet consisting of old pancakes of varying size, grey areas of frazil slush-ice and black areas of newly formed thin sheet-ice.

Hopedale dock. The uppermost 7.5 cm. of these cores were composed of slush-ice that formed from a mixture of frazil- and snow-crystals. Ice below this layer was normal sheet-ice with the typical vertical crystal structure. Fig. 10 shows successive salinity profiles taken from pure sheet-ice that had formed on a very calm night. These data were collected between December 25, 1955 and January 24, 1956. By comparing Fig. 10 with Fig. 9 the following observations can be made:

1. The salinity of the ice-sheet drops off rapidly with time.
2. Initially the surface layer of the ice-sheet has a higher brine content than the lower part of the sheet.
3. The crystal structure of an ice-sheet is one of the more important factors that control brine drainage from sea-ice (the slush-ice layer in Fig. 9 has a much higher salinity than the ice of Fig. 10 because brine drains more slowly in the former). This slower brine drainage in slush-ice is attributed to poorer vertical orientation of brine cells.

Formation of infiltrated snow-ice

Between freeze-up and January 6 the air temperature (averaged over 24 hours) remained below −10°C. (Fig. 11) and normal sea-ice growth

resulted. On January 7 the average air temperature rose to $-6°C.$ and a storm began with high winds and heavy snow (up to 30 cm.). When the storm subsided a thin layer of brine-saturated slush began to form at the base of the snow layer. The weight of the fallen snow had depressed the surface of the ice-sheet below the water-level. Brine present in the sea-ice was displaced by water from below and moved into the overlying snow until hydrostatic equilibrium was attained. This process formed a briny slush layer between the surface of the sea-ice and the overlying dry snow layer. The thickness of this slush layer increased as the warm period continued and the brine migrated through the ice until the slush layer reached a maximum thickness of 11.5 cm. In places the complete snow layer was converted to slush.

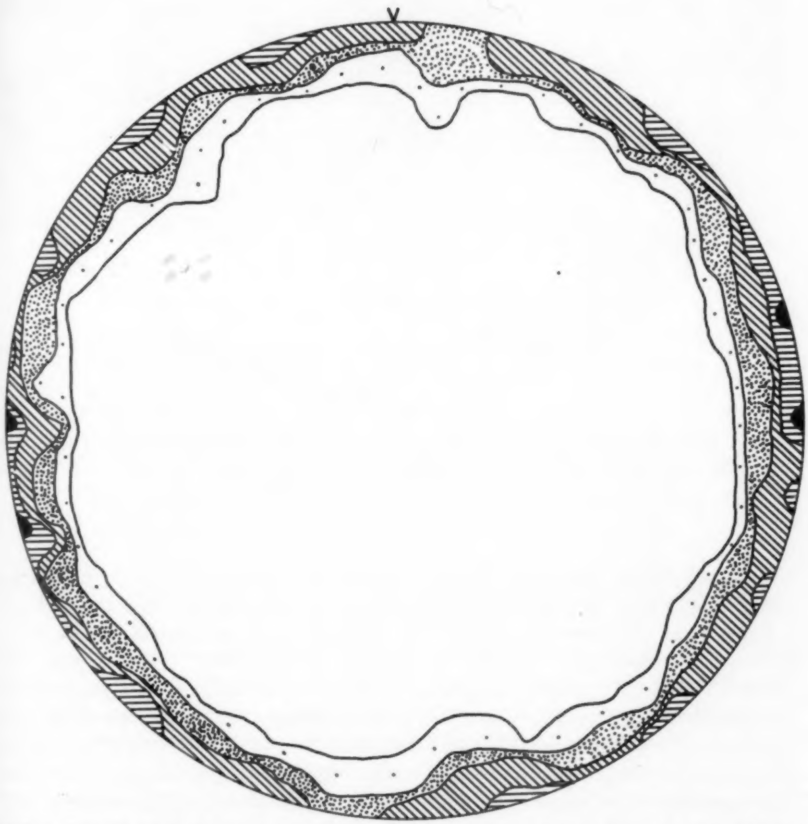

Fig. 7. Orientation of sea-ice c-axes plotted on the upper hemisphere of a Schmidt net. Diagram is in the horizontal plane, 200 grains, contours represent 1, 2, 4, 6, and 9 per cent per 1 per cent area.

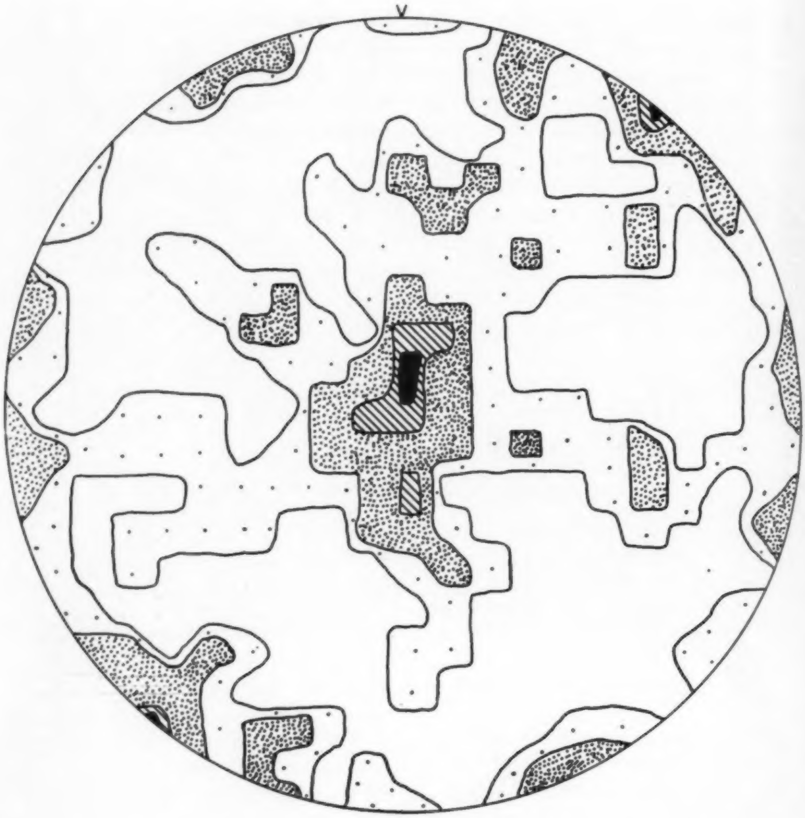

Fig. 8. Orientation of lake-ice c-axes plotted on the upper hemisphere of a Schmidt net. Diagram is in the horizontal plane, 150 grains, contours represent 1, 2, 4, and 5 per cent per 1 per cent area.

Accelerated formation of slush occurred near open tidal and thermal cracks. Early in the slush-forming process holes were drilled through the ice and artesian water fountains (up to 9 cm. high) appeared. Thick slush layers immediately formed in the vicinity of each hole. This showed that during the earlier stages of slush-formation, when the upper part of the sea-ice was colder than a certain critical temperature, the ice-sheet was impermeable and the passage of brine into the snow was inhibited. When the ice temperature rose enough for the brine pockets to interconnect and allow passage of brine through the ice-sheet, the slush layer began to form. If the entire slush layer over the whole bay was formed only by the movement of water through cracks, the slush would form quite rapidly in one or two days, instead of forming slowly during a period of weeks.

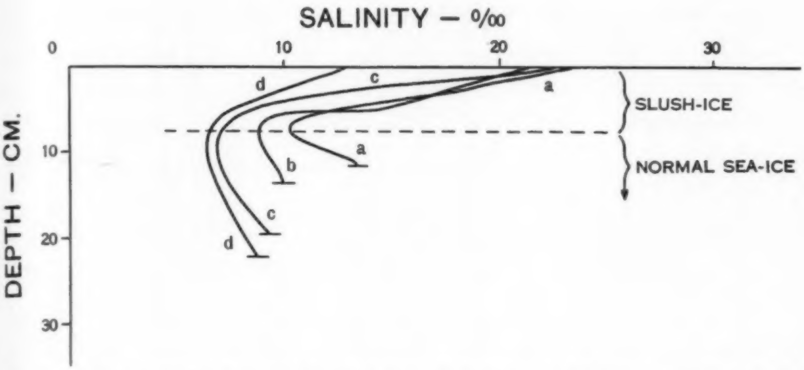

Fig. 9. Salinity profiles from sea-ice that formed during a period of wave action. Dates of profiles are: a December 23, b December 24, c December 26, and d December 29, 1955.

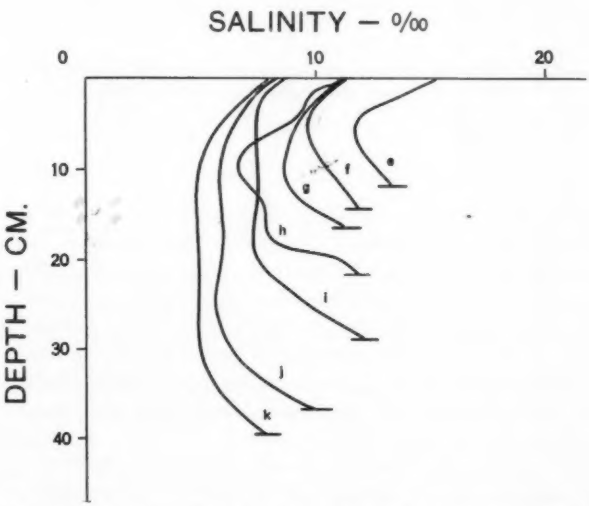

Fig. 10. Salinity profiles from sheet sea-ice. Dates of profiles are: e December 25, f December 26, g December 28, h December 30, 1955; i January 3, j January 14, and k January 24, 1956.

Taking the average salinity of the ice-sheet during the slush-forming period as 6‰ to 8‰ it is possible to estimate roughly this critical ice temperature as *ca.* —3° to —4°C. Below the critical temperature the brine content is uniformly low, whereas above the critical temperature the volume of brine increases rapidly with increasing temperature (Anderson and Weeks, 1958, Fig. 5). Most of the upward migration of brine probably occurs during the daylight hours of cloud-free days when the ice is frequently warmed to the critical temperature by absorption of radiation.

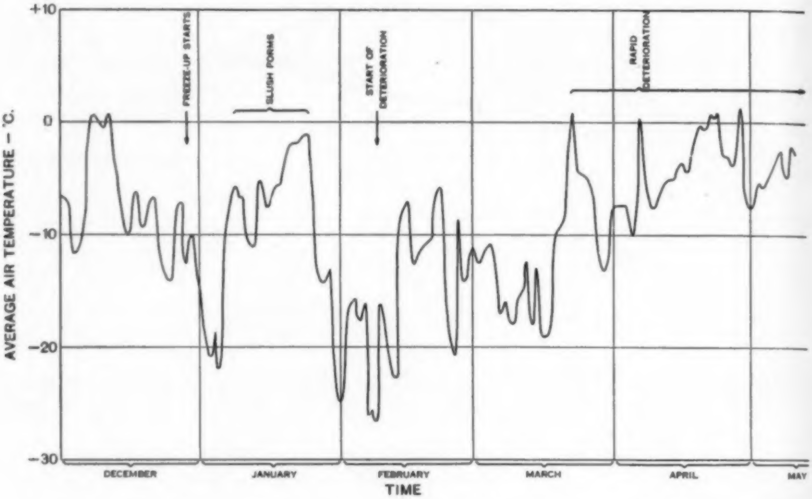

Fig. 11. Graph of daily average air temperatures recorded at the Hopedale Marconi Station from December 1955 to May 1956.

Fig. 12 shows the temperature distribution in the sea-ice cover over a typical 24-hour period (February 25, 1956). Unfortunately, thermocouples were not installed before slush-formation owing to logistic difficulties.

Fig. 13 shows the results of density and thickness profiles of snow and slush made at average intervals of 3 days during the period of slush-formation. The curves show the increase in thickness of the slush layer with time. Fig. 14 presents a comparison of the observed slush-level with the theoretical water-level, which was calculated from the measured density profiles of Fig. 13. At time A (January 6) no snow had fallen and the observed and theoretical water-levels coincided. At time B (January 8) the theoretical water-level was above the surface of the ice but no slush had started to form, whereas at times C and D (January 13 and 17) the calculated water-level was above the observed slush-level. At times E, F, and G, (January 21, 25, and 27) this relation was reversed and the upper surface of the slush-layer was well above the calculated water-level. This information indicates (a) that brine migration through sea-ice was inhibited during the first stages of slush-formation when the ice temperature was lowest and (b) that capillary action was an important factor in determining the upper level of the slush. The density of the 36.8-cm. layer of sea-ice was 0.920 gm./cm.^{3} as determined by measuring the height of the ice-surface above the water-level before the snow of January 6. Since the density of the ice would be expected to decrease with time (Fig. 21), the relative importance of capillary action would be increased.

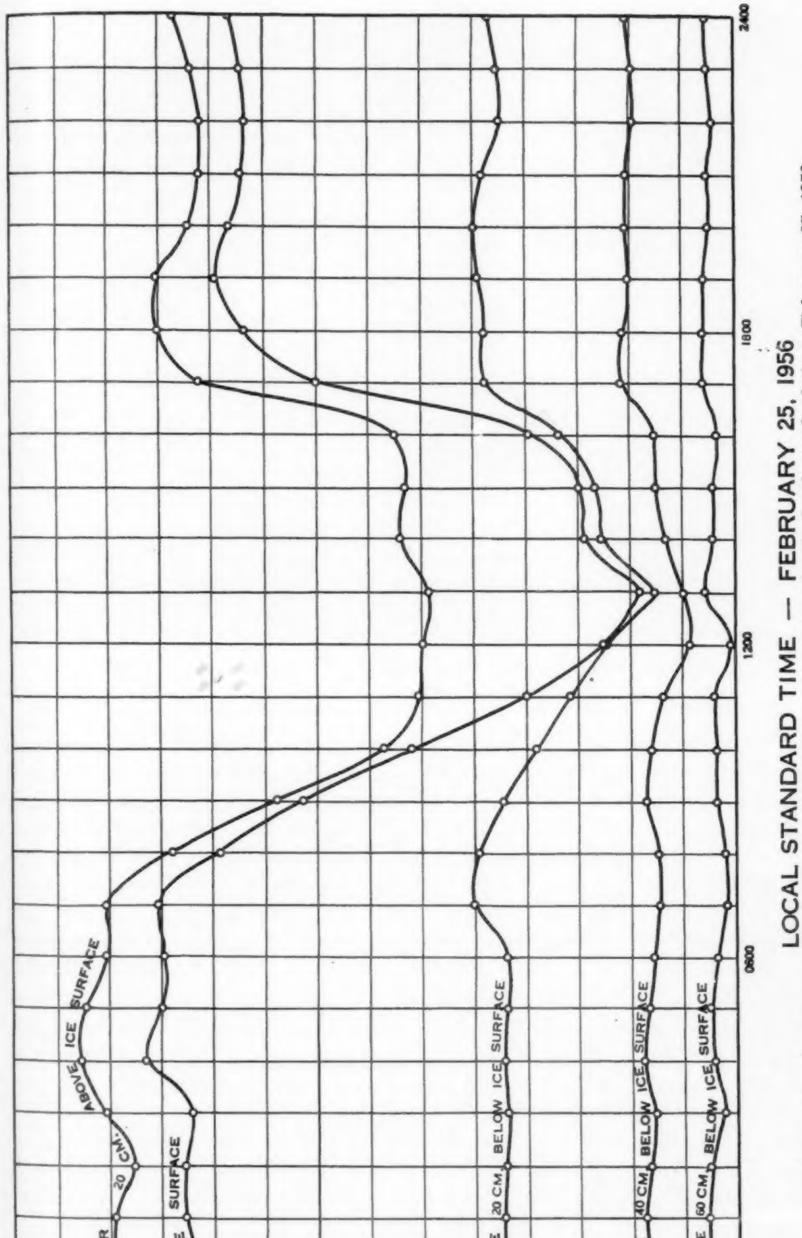

Fig. 12. Hourly averages of air and ice temperatures at various levels, local standard time, February 25, 1956.

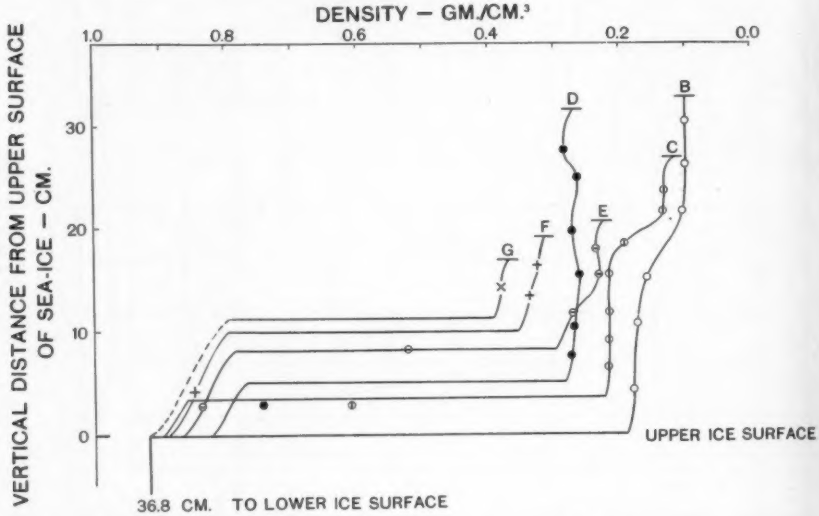

Fig. 13. Graph of snow and slush density and thickness profiles. Dates of profiles are: B January 8, C January 13, D January 17, E January 21, F Januray 25, and G January 27, 1956.

Fig. 14. Observed slush-levels and theoretical water-levels calculated from the data of Fig. 13. Dates of measurements are the same as Fig. 13, except A January 6, 1956.

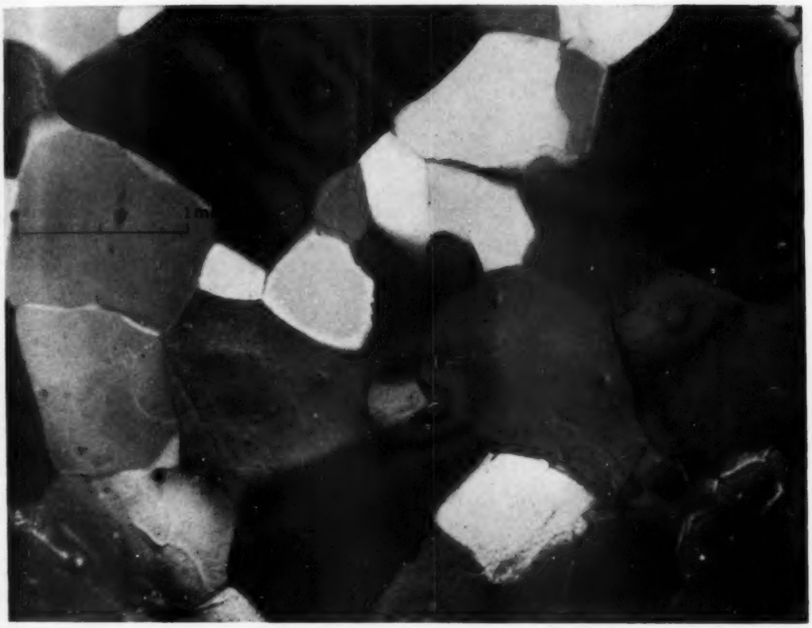

Fig. 15. Photomicrograph of thin section of infiltrated snow-ice.

When the air temperature dropped rapidly on January 25 the slush layer froze into infiltrated snow-ice. This ice layer was in general equigranular, with an average grain size of 1 mm. (Fig. 15) and had a much higher air content and therefore a lower density (approximately 0.83 gm./cm.^{3}) than normal sea-ice. A Schmidt equal-area net diagram of the c-axis orientation in infiltrated snow-ice shows a strong concentration in the vertical direction (Fig. 16). This orientation may be caused by the formation of ice overgrowths in the same orientation as the snow crystals already present.

When the slush layer froze, it had a high salt content and created an unstable situation in the ice-sheet (a layer of extremely high salinity above a less saline layer); a condition that will tend to stabilize itself at ice temperatures above the critical temperature. Curve k (Fig. 17) shows the salt content of the ice-sheet just before the period of slush-formation. This is a normal vertical distribution of salinity without irregularities. Curve l gives the salinity profile just after the slush layer froze. Note the high salinity of the slush-ice. Curves m and n show the tendency for the denser brine in the upper layers to migrate downward with time. Fig. 18 gives three salinity profiles taken during the deterioration period. They show a uniformly low salinity. The topmost few centimetres of ice (above the water-level) are almost completely free of brine.

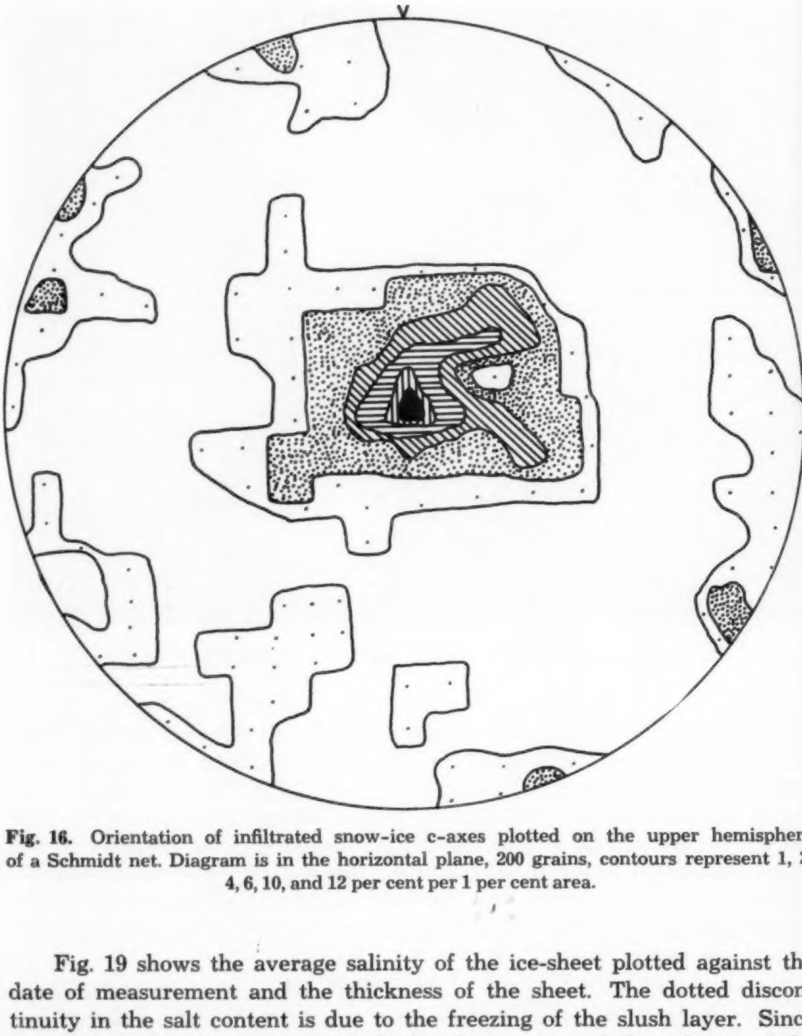

Fig. 16. Orientation of infiltrated snow-ice c-axes plotted on the upper hemisphere of a Schmidt net. Diagram is in the horizontal plane, 200 grains, contours represent 1, 2, 4, 6, 10, and 12 per cent per 1 per cent area.

Fig. 19 shows the average salinity of the ice-sheet plotted against the date of measurement and the thickness of the sheet. The dotted discontinuity in the salt content is due to the freezing of the slush layer. Since the slush layer has an extremely high salt content and the salinity of the pre-existing ice-sheet does not change appreciably during the period of slush-formation, the average salinity of the ice-sheet increases.

Accumulation of sea-ice

To forecast the growth of sea-ice it is usual to employ empirically determined curves that show the relation between observed ice-thickness and accumulated degree-days of frost. Curve A (Fig. 20) is based on ice-

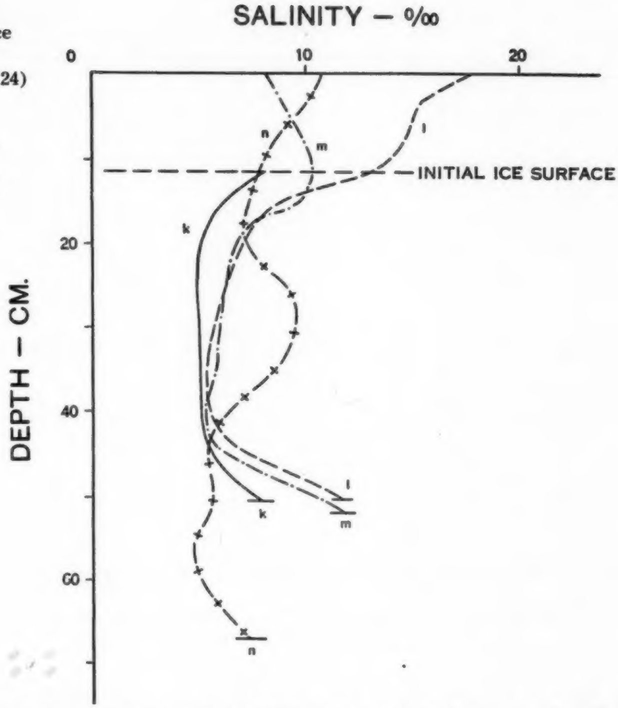

Fig. 17. Salinity profiles from sea-ice taken both before (curve k, January 24) and after the slush-layer froze (curves l, January 27, m, January 30, and n, February 16, 1956).

thickness data collected near the Hopedale dock and refers to a freezing point of -1.8°C. (the freezing point of sea water with a salinity of 32.8‰). Curve B is the empirical equation of Karelin [$N = 2.5\ (\Sigma t)^{0.52}$, where N is the ice-thickness in centimetres and Σt is the sum of the mean diurnal negative air temperature]. Karelin's equation represents the maximum sea-ice growth-rate reported in the Russian literature summarized by Lebedev (1940). The Hopedale ice-thickness data for the first 200 degree-days give a smooth, continuous curve and are in good agreement with Karelin's curve. After the period of slush-formation between 210 and 260 degree-days a scatter developed in the measured ice-thickness. This scatter was caused by the uneven distribution of wind-blown snow over the surface of the sea-ice. The heavier the weight of the overlying snow, the more the surface of the sea-ice was depressed below the water-surface, resulting in a correspondingly thicker slush layer. Consequently, after the slush layer froze, the thickest ice was located under the deepest snow-drifts.

The magnitude of this effect is evident from comparing ice-thickness surveys made on January 5, when the maximum variation in thickness owing to dates of initial freezing occurred, with surveys made on January 30 after the first period of slush-formation. The survey of January 5 showed a gradual decrease in ice-thickness from near the dock to Little Snow Island, with the minimum thickness occurring in a late-frozen lead. Ten

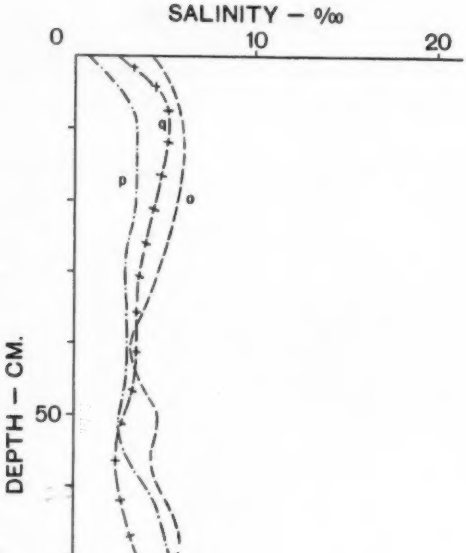

Fig. 18. Salinity profiles from deteriorating sea-ice. Dates of profiles are: o, March 16, p, April 4, and q, May 3, 1956.

measurements gave an average ice-thickness of 29.5 cm. and a standard deviation of 2.2 cm. Any normal ice-growth that took place between the time of these measurements and the slush period would tend to even out these differences because the thinner ice grows faster.

After the period of slush the ice-thickness along this same line averaged 49.1 cm. with a standard deviation of 9.3 cm. At the same time in the lee of the dock, where an extremely large snow-drift had accumulated, an ice-thickness of 95 cm. was measured.

The sudden and sharp increase in ice-thickness for a short period of time at the termination of slush-formation (see Fig. 20) occurred because the slush layer quickly solidified when the air temperature dropped. The slush froze rapidly because it lacked the protection of an insulating thick snow- and ice-layer. Therefore, this portion of the growth curve is similar to the first part of the growth curve that represents the initial freezing of the water body. After the slush layer has frozen the growth curve again parallels the original curve, although slightly offset since the accretion then takes place on the bottom of the ice-sheet. However, the thermal con-

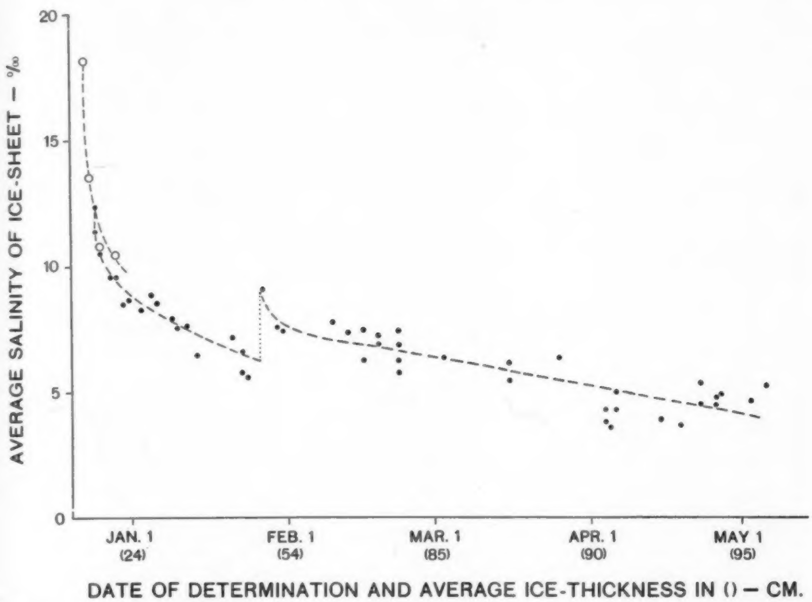

Fig. 19. Average salinity of the ice-sheet plotted against ice-thickness and data of measurement.

ductivity of slush-ice was between 10 and 75 times that of the snow, which it replaced (Mantis, 1950), so that ice accumulation on the lower surface of the slush-ice and sea-ice combination was appreciably greater than it would have been under the initial combination of snow and sea-ice. After the period of slush-formation at Hopedale the measured ice-thickness was *ca.* 20 per cent greater than that given by extrapolation of the initial growth curve.

The observations at Hopedale show that one important assumption that is usually made when computing the ice-thickness can be invalid under subarctic conditions. This is the assumption that in two similar areas that are subject to the same air temperature regime the ice-thickness will vary in inverse relation to the thickness of the snow-cover. In truly arctic regions the formation of infiltrated snow-ice does not take place to any great extent and there the assumption would be valid (Holtsmark, 1955).

Density of sea-ice

Sea-ice densities measured at Hopedale were determined in the following manner: a 7.6-cm.-diameter vertical core was taken from the ice-sheet. The core was cut into segments of approximately 7.6-cm. length. Each

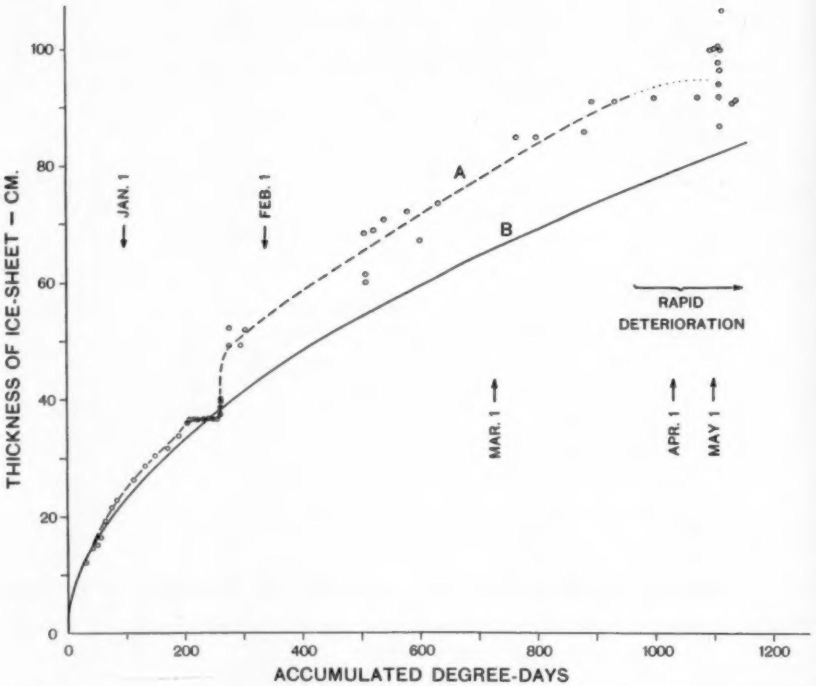

Fig. 20. Comparison of Hopedale (A) and Russian (B) degree-day curves. The sources of the curves are described in the text.

segment was measured accurately and its volume was computed. The density of each sample was determined after the cylinder was weighed. Salinities were determined from the melt water of the ice samples.

Fig. 21 shows sea-ice densities from four different periods plotted against their median locations in the ice-sheet. From examination of these data the following conclusions are drawn:

1. The density of the infiltrated snow-ice is in general lower than that of normal sea-ice.
2. There does not appear to be a systematic variation in density with depth of the sample in the ice-sheet.
3. In general the average density of the ice-sheet decreases with the age of the sheet [period 1, $\rho = 0.920$; period 2, $\rho = 0.904$; period 3, $\rho = 0.880$]. Unfortunately, densities of newly formed sea-ice at Hopedale were not determined. However, measurements at Thule, Greenland the following winter showed that the average density of newly formed sea-ice was *ca.* 0.945 gm./cm.[3]. This density decrease with time is quite understandable since during the aging

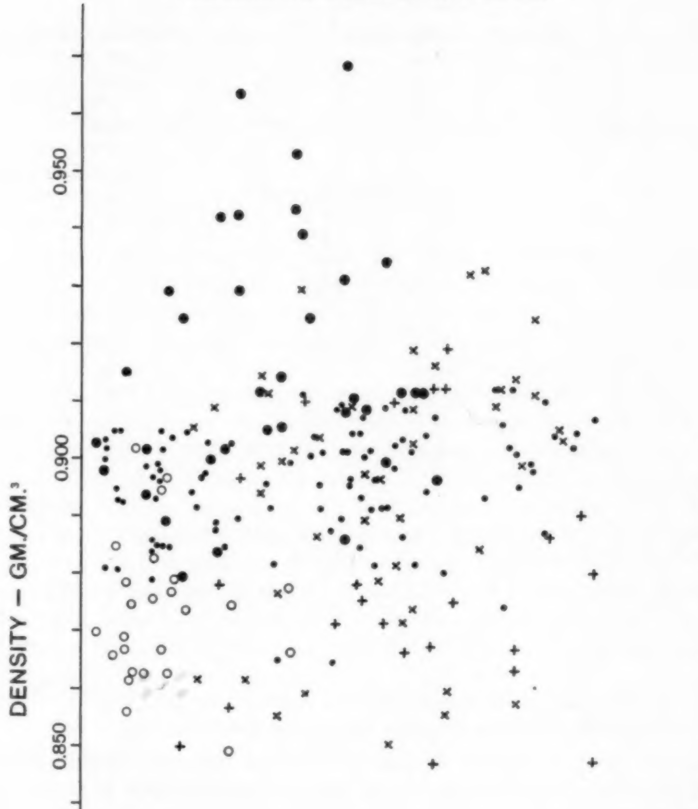

Fig. 21. Density measurements of sea-ice at Hopedale.

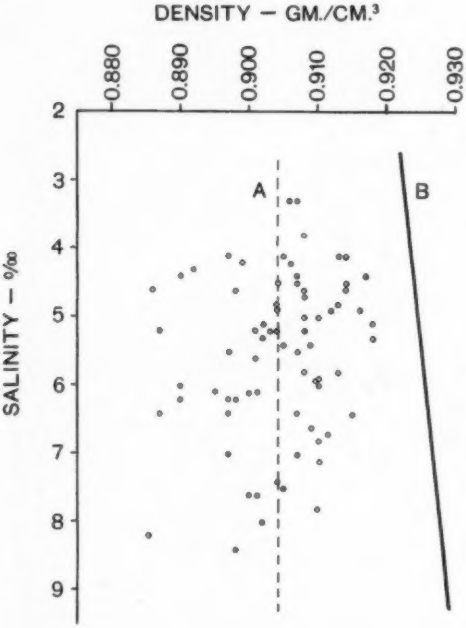

Fig. 22. Comparison of ice-densities measured during the period of March 11 to 19, 1956, with the theoretical density of air-free sea-ice at —15°C. (line B).

process part of the brine cells are replaced by ice. The ice of period 4, however, has an average density of 0.902 gm./cm.^{3}.

Fig. 22 presents sea-ice densities measured between March 11 to 19 plotted as a function of salinity. Line A is a least-squares fit of the data. Line B (Zubov, 1945) shows the theoretical density of air-free sea-ice at —15°C. (the average air temperature during this period of time). Comparing these two curves it can be seen that since the sea-ice of this period has an average density of 0.904 gm./cm.^{3} instead of 0.926 gm./cm.^{3} it contains 2.4 per cent by volume of air.

Crack-formation

Observations were made on the distribution and history of tidal and thermal cracks in Hopedale Bay. Fig. 1 shows the location of the major zones of thermal contraction cracks in the ice-sheet. The following conclusions are drawn:

1. Thermal cracks usually form between headlands (points) or other topographic irregularities. These cracks form in the same locations year after year.
2. The ice-crystals found in narrow, healed cracks have their c-axes horizontal and in line with the crack.

3. Healed cracks appear to be stronger than the normal ice-sheet. Once a crack has been frozen it usually does not break open again; but similar cracks will form parallel to it.
4. Cracks caused by tidal motion are localized near shore.

Acknowledgements

The field observations on which this paper is based were made while the authors were associated with the Geophysics Research Directorate, Air Force Cambridge Research Center (W.F.W.) and the U.S. Navy Hydrographic Office, Applied Oceanography Branch, Washington 25, D.C. (O.S.L.). One of the authors (W.F.W.) would also like to aknowledge the sponsorship of the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command, under Contract No. AF 19 (604)-3062. The density determinations presented in Fig. 21 were taken by P. Pomroy (February 10 to 12), T. R. Butkovich (March 11 to 19), N. Costes (April 11 to 16), and Dr. A. Assur (April 27 to May 5). We are also indebted to them for many profitable discussions in the field. Thanks are also due to W. H. Hymes who assisted in the field observations. More detailed analyses of specific problem areas investigated during this project that have been published or that are now in press are: Anderson and Weeks (1958), Butkovich (1956), Weeks (1958), Weeks and Anderson (1958 a, b).

References

Anderson, D. L. and W. F. Weeks. 1958. A theoretical analysis of sea-ice strength. Trans. Am. Geophys. Union 39:632-40.

Armstrong, T. 1954. Sea ice studies. Arctic 7:201-5.

Bader, H. 1957. Ice drills and corers. J. Glac. 3:30.

Butkovich, T. R. 1956. Strength studies of sea-ice. SIPRE Research Report No. 20, 15 pp.

Holtsmark, B. E. 1955. Insulating effect of a snow cover on the growth of young sea ice. Arctic 8:60-65.

Lebedev, V. V. 1940. New formulas on the growth of ice in arctic rivers and seas. Meteorologiya i Gidrologiya 6:40-51.

Mantis, H. T. *et al.* 1951. Review of the properties of snow and ice. SIPRE Report No. 4, 156 pp.

Weeks, W. F. 1958. The structure of sea ice. A progress report. NAS Sea Ice Conference Proceedings.

Weeks, W. F. and D. L. Anderson. 1958a. Sea ice thrust structures. J. Glac. 3:173-5.

——————————1958b. An experimental study of the strength of young sea ice. Trans. Am. Geophys. Union 39:641-7.

Weeks, W. F. and O. S. Lee. 1957. Observations on the growth of sea ice at Hopedale, Labrador. (Abstr.) Trans. Am. Geophys. Union 38:412.

Wilson, J. T., J. H. Zumberge, and E. W. Marshall. 1954. A study of ice on an inland lake. SIPRE Research Report No. 5, 78 pp.

Zubov, N. N. 1945. Ledy arktiki (Ice of the Arctic). Moscow: Izdatelestvo Glavsevmorputi, 360 pp.

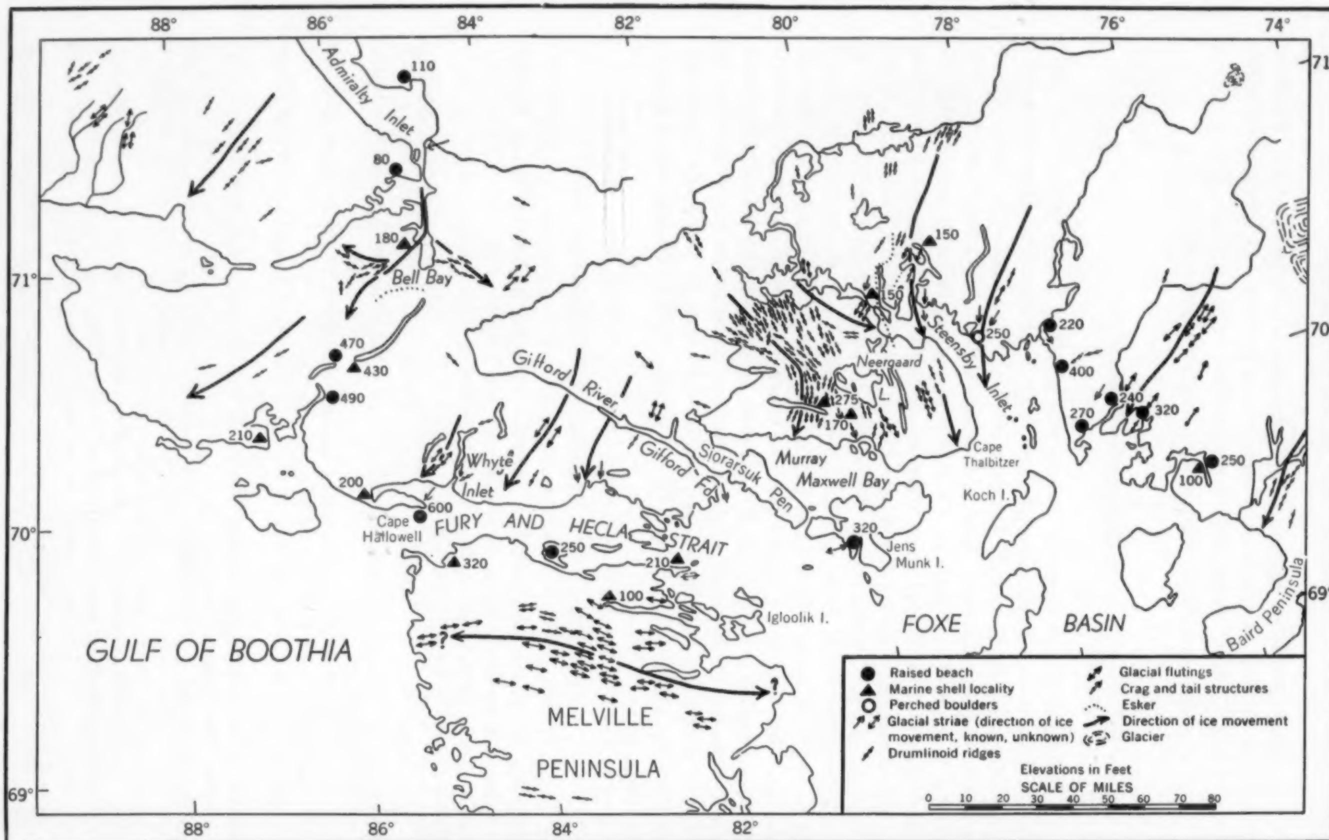

Fig. 1. Map showing features indicating marine transgression and ice movement.

PATTERNS RESULTING FROM GLACIER MOVEMENTS NORTH OF FOXE BASIN, N.W.T.*

R. G. Blackadar†

Introduction

Foxe Basin, a relatively shallow inland sea, is bounded on the north and east by Baffin Island and on the west by Melville Peninsula. It opens to the south into Hudson Bay by way of Foxe Channel; on the northwest, Fury and Hecla Strait, a narrow, deep channel, connects it with the Gulf of Boothia.

The first white men to see the part of the region to be discussed in this paper were members of an expedition under the command of Sir Edward Parry, R.N., who passed the winter of 1822-3 at Igloolik, just south of the eastern entrance to Fury and Hecla Strait. C. F. Hall, an American, visited the region in the late 1860's in the course of his expeditions in search of relics of the ill-fated Franklin expedition. In 1911 a Canadian expedition, based at Arctic Bay, several hundred miles to the north, explored part of the western limits of the region and in 1913 A. Tremblay, a member of a private prospecting expedition working out of Pond Inlet, travelled through much of the area. Members of the Danish Fifth Thule Expedition examined parts of this area between 1922 and 1924 and in the reports of T. Mathiassen are found the first precise comments on geology and physiography (Mathiassen, 1933, 1945). Parts of the area were examined by members of the British-Canadian Arctic Expedition in the years 1937-41 and by members of the *Nauja* Expedition in 1949.

This paper incorporates data collected by the author during two field seasons, 1956 and 1957, while conducting a mapping programme for the Geological Survey of Canada in the northern Foxe Basin district and expands information shown on the 1958 edition of the Glacial Map of Canada.

Physiography

The map-area includes uplands, plateaux, and lowlands. As outlined by Fortier (1957, p. 398) these are: on the east the Baffin uplands; in the south-central and western parts, the Foxe Basin lowlands and the Southampton-Melville uplands; in the northern part of the area the Jones-Lancaster plateaux and the Boothia-Regent lowlands.

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In general, the areas underlain by Precambrian rocks, granites and older sedimentary-volcanic rocks, and younger sandstones and slates, are high and form the uplands with some elevations in excess of 2,000 feet, whereas the parts of the district underlain by Palaeozoic strata form the lowlands, which rarely rise above 100 or 200 feet above sea-level. Thus both north and south of Fury and Hecla Strait the land rises steeply from the sea to form a rather rolling upland surface at between 1,000 and 1,500 feet in which drainage is well established. A similar condition prevails along the east coast of Foxe Basin whence the land rises steadily towards the mountains of eastern Baffin Island. In contrast, the islands in the northern part of Foxe Basin are very low, covered with innumerable small ponds and lakes and surrounded by extensive tidal flats.

Although Precambrian areas are generally high, north of Steensby Inlet a low valley floored by granitic gneiss extends northward, bounded on the east by the Baffin uplands of Precambrian rocks and on the west by Palaeozoic outliers of the Jones-Lancaster plateaux; north of Murray Maxwell Bay limestone plateaux rise above low Precambrian areas. These features may be the results of large northwest-trending block faults.

The greater part of the map-area is mantled by surficial deposits. In many cases these deposits form only a thin veneer over the bedrock. This is especially true of the raised beaches. Elsewhere, however, drift deposits composed of light-grey clay and angular limestone fragments appear to exceed several hundred feet in thickness. Such an area, south of Neergaard Lake is illustrated in Fig. 2. Here light-coloured, unconsolidated material lies unconformably above darker Precambrian granitic gneiss. In this locality the drift is about 200 feet thick.

Ice movement features

In the course of preliminary work for the geological reconnaissance in northern Foxe Basin district the writer examined about 1,600 trimetrogon air photographs. It soon became apparent that in many parts of the area terrain patterns were primarily the result of glaciation. Fig. 1 presents the results of the plotting of data from both air photo study and ground observations. Areas in the interior were not reached during the reconnaissance mapping programme but sufficient key areas were seen to warrant extrapolation by means of the air photographs to these inland stretches.

The features plotted include drumlinoid ridges, glacial flutings, crag-and-tail structures, and glacial striae. Of these the drumlinoid ridges are the most widespread and are best developed north of Murray Maxwell Bay near the centre of the map-area. Here a clayey soil containing angular slabs of limestone, some several feet in length, has been moulded into a series of long, parallel ridges. The size of the drumlinoids varies greatly throughout the area, ranging from those shaped like over-turned canoes, slightly steeper at one end than at the other and averaging a few hundred feet in length, to those illustrated in Fig. 2, which exceed a mile in length and are

Photo: R.C.A.F.

Fig. 2. Looking west over Neergaard Lake, Baffin Island. Drumlinoid terrain lies south and west of the lake and occupies a 500-foot high plateau underlain by Precambrian rocks.

at least 50 feet high and may be 1,000 feet wide. These latter grade into glacial flutings, structures developed in drift deposits and differing from drumlinoids in that the relatively short *en echelon* pattern characteristic of drumlinoid fields is replaced by parallel ridges and furrows, which may extend for many miles.

Crag-and-tail structures were observed in several parts of the map-area. Southeast of Neergaard Lake isolated knobs of bedrock rise about 50 feet above a low, drift-covered plain. The northwest faces of these knobs are steep and rugged, whereas on the southeast side the bedrock is smooth and rounded, and beyond the outcrop a ramp or tail of drift merges the outcrop knob with the plain.

Fig. 2 primarily shows the pattern developed by the ice as it moved across the drift-covered area west of Neergaard Lake. The more regional trend of the ice-flow features is illustrated by Fig. 1. The Neergaard Lake photograph also shows other features of interest. The Precambrian rocks

Photo: R.C.A.F.

Fig. 3. Northern Melville Peninsula, looking east toward Foxe Basin. Fluted drift and sculptured bedrock in foreground.

that form a steep, north-facing scarp, overlain by drift on the southwest side of the lake, have been mentioned. The light-coloured patch on the extreme left hand side of the illustration is a flat-topped, sandy moraine, which rises about 300 feet above the surrounding plain. The sides of this hill are steep, sloping at about the angle of repose of the sandy material. Just to the west, above this feature are curved traces of former beach-lines and to the east, in the foreground, can be seen the innumerable small ponds and lakes so characteristic of low, glaciated Precambrian bedrock terrain.

The glacial flutings developed south of Fury and Hecla Strait are shown in Fig. 3. The east-facing bedrock hills suggest, but by no means prove, that the ice movement here may have been from the southeast.

Areas of drift showing no pronounced orientation, such as that seen in Fig. 4, cover large expanses; they are not indicated on the maps accompanying this paper. In the foreground of Fig. 4 are a few patches of polygonal patterned ground, a feature commonly found in regions underlain by permafrost.

Photo: R.C.A.F.

Fig. 4. Unoriented drift east of Bell Bay, northern Baffin Island. Light coloured surface in upper left is presumed to be underlain by Palaeozoic sedimentary rocks.

Eskers are not abundant in the region but several prominent ones were mapped. That southwest of Bell Bay, in the northwestern part of the map-area, forms an outstanding landmark, rising 170 feet above the surrounding plain covered with numerous raised beaches. From a distance the esker presents a rugged, serrated skyline, so that it might easily be mistaken for a ridge of bedrock.

Ice movement patterns

At present small ice-caps exist on high land in the eastern and north-eastern parts of the map-area. In the past these were undoubtedly more extensive, but the relationships between the present ice-caps and the ice-flow features in the different parts of the area, as illustrated in Fig. 1, are not known.

In the northwestern part of the area the trend of glacial features is southwest, whereas east of Admiralty Inlet it is mainly southeast. At the south end of Admiralty Inlet Mathiassen observed glacial striae at south 80° west and these data are plotted on Fig. 1.

North of Gifford River glacial features are few, but south of this river and north of Fury and Hecla Strait the trend prevailing in the northwestern part of the map-area is continued. Glacial striae at Cape Hallowell and Whyte Inlet parallel the trend of drumlinoids and other features, a trend that crosses Gifford Fiord and River at right angles. The fiord, apparently a true fiord, being more than 600 feet deep with a shallow bar at the mouth and with 700- to 800-foot cliffs rising abruptly from the sea, may have been formed by glacial action along a major fracture in the bedrock. This erosion may have taken place early in the period of glaciation that caused the ice-flow features in the map-area; later, for some reason, the ice could no longer escape from the depression, eventually the fiord became filled with ice and was overridden by ice moving in a southwesterly direction. This may be the explanation for the presence of such a prominent feature athwart the prevailing trend lines. Indeed, at the mouth of the fiord Mathiassen mapped striae at south 10° east (see Fig. 1), which may reflect this earlier down-fiord movement.

On the south side of Fury and Hecla Strait the prevailing trends of glacial flutings are southeast and these trends are in accord with striae at the eastern entrance to the strait and on Jens Munk Island. Insufficient evidence is available from northern Melville Peninsula to determine the direction of ice movement; there is no reason to assume that the ice moved into Foxe Basin. Indeed, certain features shown in Fig. 3 suggest that movement may have been from the southeast across Melville Peninsula.

North and especially east of Foxe Basin the land rises gradually and merges with the high, uplifted mountains of eastern Baffin Island. East of Steensby Inlet and north of Baird Peninsula glacial flutings and striae trend southwesterly and it is tempting to suggest that the ice moved from the highlands in the northeast; however, this is only speculation as directional features were not observed by the author.

North and west of Steensby Inlet several different trends are discernible. The source of the ice that caused them is unknown, but they may have been formed by lobes extending from ice centred in the highlands of northeastern Baffin Island. North of Steensby Inlet and Murray Maxwell Bay striae and crag-and-tail structures indicate movement from the north. It would appear that lobes of ice moving southward from northeastern Baffin Island may have converged in the vicinity of Steensby Inlet and thence moved southward into Foxe Basin.

Marine features

The most striking terrain features in the northern Foxe Basin region are the abundant raised beaches. Indeed, islands like Igloolik, Jens Munk, and Koch, are almost devoid of rock outcrops and are composed primarily

Photo: R.C.A.F.

Fig. 5. Eastern Jens Munk Island, showing numerous emerged strand-lines, innumerable ponds, and broad tidal flats, which characterize the low islands and coasts of Foxe Basin.

of reworked limestone and shale fragments. Fig. 5 is typical of this terrain. The light-coloured beach material is separated by shallow ponds or swampy ground, which shows as dark-coloured patches on the air photographs. More than forty successive emerged strand-lines were observed inland from Cape Thalbitzer across a distance of 8 miles. Raised beaches of dubious origin have been reported from the interior of the map region; in some cases these may be the result of deposition in glacial lakes, but others may be of marine origin. Too little information is available to consider these areas at present.

Fig. 6 is an attempt to portray the maximum extent of the last marine submergence. Data used to determine the upper limits are the presence or absence of strand-lines or spits, marine shells, perched boulders, wave-washed outcrops, wave-cut cliffs, and wave-washed drift areas. Fig. 7 illustrates this last criterion. Here well-formed beaches wrap around, but do not cover an elevated nose of drift showing south-trending flutings. Such a hill probably formed a point or island during the maximum submergence

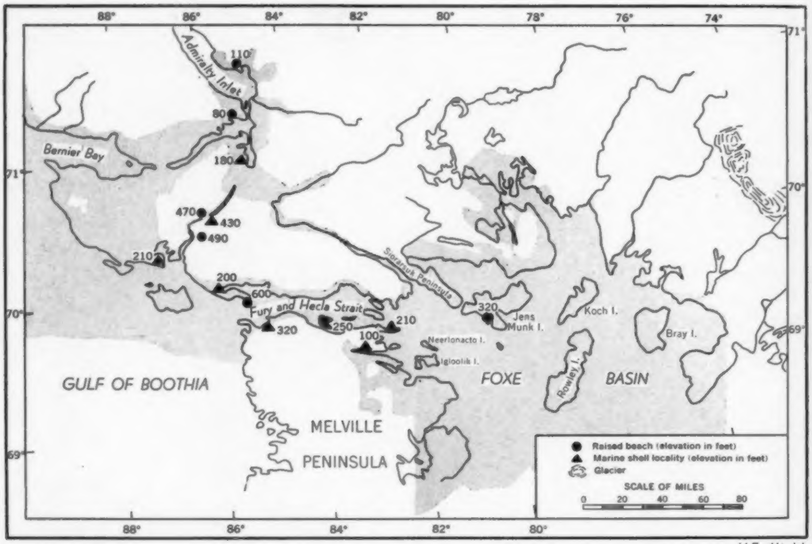

Fig. 6. Map showing presumed extent of marine transgression.

of the area. It is considered improbable that the flutings could be so well preserved had the land been covered by the sea. Areas such as that shown in Fig. 7 commonly are lower in elevation than the highest well-preserved beaches in the map area. It is possible that such places were covered by ice during the period of maximum submergence when the high-level beaches were being formed. On the other hand, land emergence may not be proceeding at equal rates over the entire region and although the highest beaches in the eastern part of the area are lower than those at Cape Hallowell on Fury and Hecla Strait, they may possibly be contemporaneous. In general, the elevations noted on Figs. 1 and 6 are those of the highest well-preserved beach in a particular area and the maps should not be considered as a representation of conditions at any specific time.

Rate of emergence

A radiocarbon dating is available from archaeological material collected by J. Meldgaard from a raised beach on Igloolik Island (Meldgaard, 1958). An age of 1750 B.C. ± 300 years is quoted for the material, which came from a beach 51 metres above present sea-level. This suggests a rate of emergence of about 4.5 feet per century. This value cannot, of course, be extended with any assurance to other parts of the region.

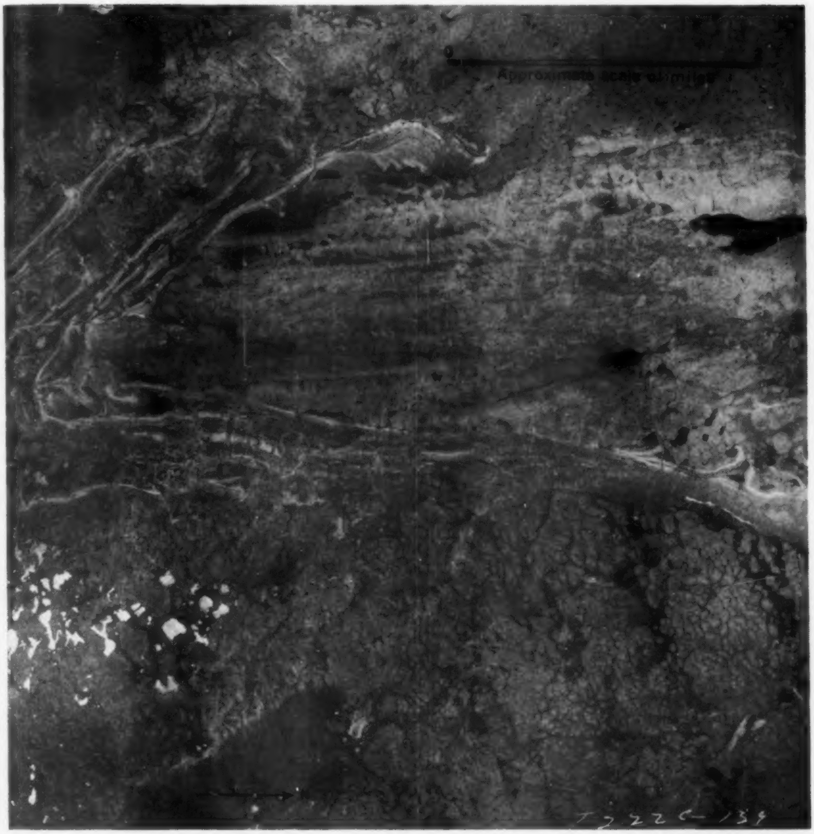

Photo: R.C.A.F.

Fig. 7. Emerged strand-lines formed around fluted drift ridge. Low outcrops of granite are visible on both sides of the hill. Note the unoriented drift areas in lower right, which are a few hundred feet lower than the top of the ridge. Six miles north of the east entrance to Murray Maxwell Bay, Baffin Island.

References

Mathiassen, T. 1933. Contributions to the Geography of Baffin Land and Melville Peninsula. Report of the Fifth Thule Expedition, 1921-24, vol. 1, No. 3, 104 pp.

——— 1945. Report on the expedition. Report of the Fifth Thule Expedition, 1921-24, vol. 1, No. 1, 134 pp.

Meldgaard, J. 1958. Personal communication. Analysis made by Radiocarbon Dating Laboratory, Nationalmuseet VIII Dept., Copenhagen, Denmark. Analysis K 505.

Fortier, Y. O. 1957. The Arctic Archipelago, *in* Geology and Economic Minerals of Canada, 4th edition. Ottawa: Department of Mines and Technical Surveys, 517 pp.

CONCEPTS OF SOIL FORMATION AND CLASSIFICATION IN ARCTIC REGIONS*

J. C. F. Tedrow and J. E. Cantlon†

Introduction

Some eighty years ago, when Dokuchaev (Margulis, 1954) distinguished five natural soil zones — tundra, podzol, chernozem, desert, and laterite — the stage was set for a systematic study of soils as naturally occurring bodies. Of these, the tundra has received by far the least attention. European investigators, notably the Russians, have made many studies of the northern regions but in North America few reports of scientific studies in the Arctic have been made by trained soil scientists. In this paper some relationships of soil-forming processes operating in the various northern regions, especially in connection with the podzolic and the so-called tundra processes, are presented; and some problems in connection with vegetation-soil relationships and the classification and mapping of soils are outlined.

In the formation of soil the most important factors that have to be taken into consideration are climate, parent material, biotic elements, relief, and time. The interaction of these five factors, operating at different intensities will produce soils with different properties. Given sufficient time, adequate drainage and depth of mineral material on the more level, stable landforms, a mature or zonal soil will tend to form. In the tropics the zonal soils will have a reddish appearance, in the prairies a dark brown to black, whereas in the northern forested regions the upper mineral horizons will have a bleached appearance. Distinct as these zonal soils are, they have at least one important feature in common, that is, they form under conditions of adequate drainage. Tundra soils, however, form under conditions of poor drainage and it may be somewhat fallacious to speak of them in terms of zonal soils as is done with podzols and chernozems.

Soil processes in the northern forest and tundra regions

Tundra (Tedrow *et al.* 1958) soils are those widespread, poorly drained soils of the arctic regions that are mineral in character and underlain by

* Journal Series paper of the New Jersey Agr. Exp. Sta., Rutgers University, the State University of New Jersey, Department of Soils; and Publication No. 58-4 of the Department of Botany, Michigan State University.

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permafrost. Partly water-logged conditions and glei-ing are usually present in the upper mineral horizons. The organic horizon at the surface is usually several inches thick and upper horizons tend to be strongly acid in reaction. Upland tundra soils, while poorly drained, occupy the higher sites on sloping land and rounded hilltops. Meadow tundra soils occupy the lower positions, the flatter areas, and situations of very poor drainage. The pioneer work of Dokuchaev, Sibirtzev, Afanasiev, and others provided for the recognition of tundra soil in idealized, global classification diagrams. Sibertzev (Glinka, 1928; Margulis, 1954), designated tundra soil as a zonal soil in the 1890's; however, because of the paucity of information existing on tundra soils at that time he did little more than make provision for it in his schematic diagram. Marbut (1927) in his proposal categorizing major kinds of soils recognized the tundra soil as a normal soil of the cold zone just as he did the podzol, chernozem and laterite in other climatic zones. He stated:

> "The normal profile. Experience has shown that in every region having what may be defined as normal relief, there is a normal soil profile. By normal relief is meant the relief that at the present time characterizes the greater part of the earth's surface, and for the purpose of this discussion, may be described as smooth, undulating or rolling, with the relation to drainage such that the permanent water-table lies entirely below the bottom of the solum."

Further, in his discussion of immature soils, Marbut (1928) states:

> " . . . another factor which causes some of the soils of a given region to be immature in their development is that of poor drainage. Mature soils attain maturity only under the influence of normal, good drainage. Excessive amounts of water and especially a high water-table or high ground-water prevent the development of a complete, normal profile."

Unquestionably the soil profiles that have been long recognized as tundra form under conditions of poor drainage (Neustruev, 1927). The tundra profile shows all the characteristics of gleization, and free water is commonly present up to the surface of the soil. This wet condition is greatly influenced by the presence of permafrost, usually at depths of from 1 to 2 feet. Although soil scientists point out that a zonal or mature soil can form only under conditions of free drainage, they nevertheless state that tundra soil is a zonal soil. This direct contradiction that originated over a quarter of a century ago should be done away with.

It has been suggested that it would be more appropriate to designate tundra soil as an intrazonal (hydromorphic) rather than a zonal soil (Gorodkov, 1939; Robinson, 1949; Tedrow *et al.*, 1958).

A number of qualitative soil-forming processes operate in the several climatic regions of the earth, such as those of laterization and podzolization. These processes tend to be intensified or weakened along climatic gradients. Unfortunately, some writers imply that the podzolic process gives way northward to a special tundra soil-forming process unique to the arctic regions; or that a weak podzolic process is operating in tundra soils. Neither of these concepts is supported by facts.

Much of the misunderstanding results from the futile attempt to relate a podzol, which forms under conditions of free drainage, to a tundra soil, which forms under conditions of highly impeded drainage. A more orderly picture of relationships emerges when one compares the mature soils in the northern podzol zone with mature soils locally found in the arctic regions on well-drained sites, and the so-called tundra soils with the northern forested glei soils.

North of the zone of maximum podzolization, the podzolic process weakens but does not grade into a special type of soil formation unique to the arctic regions (Gorodkov, 1939; Tedrow *et al.*, 1958). Instead, it continues to operate on the well-drained, stable sites (Fig. 1). As mean summer temperatures become lower and precipitation decreases, the process operates at a very much reduced intensity. But it is of sufficient magnitude to bring some mineral elements into solution. These apparently recombine with the organic residues to produce the brown colour in the upper horizon. Leaching is very feeble, and no visual evidence of translocation of mineral elements is normally noted in the profile. Meinardus (1930) describes some weak processes operating in the well-drained shallow soil areas of Spitsbergen that involve leaching of divalent cations and conversion of some FeO to Fe_2O_3. Leahey (1949) mentions reddish-brown forested soils of the Yukon Territory outside the permafrost region and mineral soils within it that have a thin, reddish-brown solum. Kellogg and Nygard (1951) report subarctic brown forest soils of central and southern Alaska with various yellow and brown sola.

Arctic brown are those soils of the arctic regions that are mineral in character and form under free drainage. Their areal extent is small and is confined primarily to escarpment areas, ridges, terrace edges, and stabilized dunes. The upper mineral horizon approximates a dark-brown colour and is acid in reaction. Colours grade through various yellow-browns and grey-browns with depth. The active layer is usually deep. Arctic brown soil has been reported in Alaska north of the 71st parallel (Tedrow and Hill, 1955). In this soil the podzolic nature is so weakly developed that it can be detected only by chemical and mineralogical techniques (Drew and Tedrow, 1957). Pierre Dansereau (personal communication) supplied the authors with samples and descriptions of soils from Baffin Island that correspond to those of the arctic brown soils. This suggests that the brown soils are also present in the Eastern Canadian Arctic. At higher altitudes in the Arctic, as in the Brooks Range, the soil-forming process in the well-drained sites becomes so feeble that it is questionable whether it actually should be designated as a process. The solum in well-drained areas may be only a few inches thick. These soils resemble those assigned to polar desert by Gorodkov (1939).

Just as the very local brown surface soils of the Arctic are a northern counterpart of the podzols, so the widespread tundra soils, forming under impeded drainage, are a northern counterpart of the glei soils of the northern forested regions (Fig. 1). Northward of the forested areas the impermeable permafrost layer is close to the surface; this results in a very

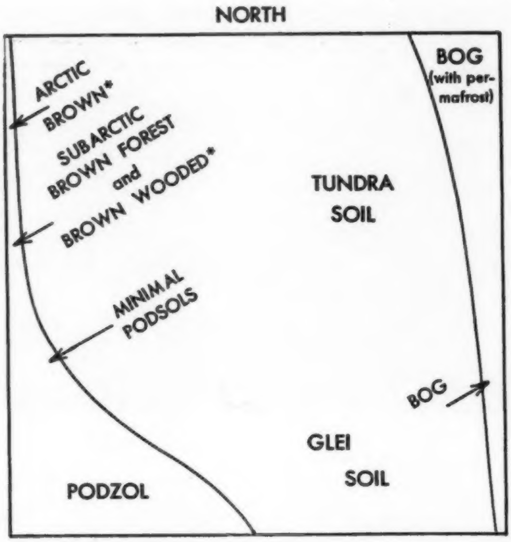

Fig. 1. Podzols grade northward into arctic brown and related soils, whereas glei soils grade into tundra. The graphic generalization indicates that northward the tundra and bog soils become dominant areally, whereas arctic brown soil is present only in small, localized areas (Lithosols excluded).

* Permafrost is usually deep and apparently has only minor influence on soil features.

high proportion of poorly drained land. The process of gleization, although operating on great expanses, weakens in northern areas because of the reduced chemical and biological activity, short growing season, and low temperature.

In both wet and well-drained sites downslope movement combines with frost processes, tending to disrupt any orderly morphology. This downslope movement increases with steepness of slope. On slopes of 3 to 5 per cent downslope movement of soil does not appear to be a major factor. But as slopes increase to the 20 to 40 per cent level the process becomes intense. These disturbances manifest themselves in an erratic appearance of the soil profile and indirectly by the unique surface characteristics of the landscape (Washburn, 1956; Sigafoos and Hopkins, 1952) and related evidence (Figs. 2, 3, 4, and 5).

Apparently, frost processes cause a certain amount of physical displacement of the mineral and organic matter. Despite the volume of descriptive literature available on the subject of frost action, virtually no quantitative measurements on rates of displacement and movement of soils are available. Until they are, one can only speculate as to the rate at which the cryopedologic processes operate. On the better-drained glei soils, such as those of the higher and gently sloping terrains, the processes of soil formation operate at an intensity sufficient for a number of genetic properties to become evident in the profile. The upper horizons display more yellow-brown and related colours near the surface, grading into duller colours with depth.

Fig. 2.

Fig. 3.

If cryopedologic processes were operating at a rapid rate in these soils, colour differences would not be detected between the various upper horizons and a more homogeneous colour would be present throughout the active zone.

If the soils and soil formation processes in the arctic tundra region are examined and compared with their counterparts of temperate regions, we find that the mature, normal soil (in the sense of Marbut and earlier European investigators) is not the most extensive. The profiles of these highly local arctic brown soils reflect the full impact of the regional climate, unmodified by waterlogged conditions or major frost displacement. If one chooses to equate zonality with these former unmodified conditions, then

Fig. 4.

Fig. 5.

Figs. 2 — 5. Some features indicating instability of soils on the steeper terrain are the presence of (Fig. 2.) lobate terraces near the Jago River about 10 miles north of McCall Glacier; (Fig. 3) rock broken off the outcrop and moved downslope near Umiat, Alaska; (Fig. 4) highly disturbed soil profiles resulting from solifluction processes (the debris at the foot of the slope exceeds 20 feet in thickness), photo taken along the Colville River with Mt. Umiat in the background; and (Fig. 5) solifluction lobe covering part of a terrace, photo taken near the Pitmega River 40 miles east of Cape Lisburne.

tundra soils should not be considered zonal. To assign zonal status to tundra soils equates zonality with simple regional dominance. The implied idea that the zonal profile fully reflects the impact of the regional climate must then be abandoned. On tundra soils we have the unusual circumstance that

the operation of the regional climate brings about its own suppression as a soil-forming factor through the formation of the impervious frozen layer. Here minor regional differences of climate have much less effect on the soil pattern than local micro-variations in drainage.

Vegetation-soil relationships, micro-relief, and soil classification problems

Relation between soil type and vegetation. In the Arctic, as well as in most other climatic regions, the moisture status of the soil exerts a marked selective influence on the plant populations. Thus, when on the basis of profile morphology the soils of arctic Alaska are arranged into a sequence (Fig. 6), representing a drainage catena (Tedrow *et al.*, 1958), the associated vegetation normally shows a characteristic sequence of communities (Fig. 7). On the deep and the shallow well-drained soils, the regularity in soil-vegetation relationships, although by no means perfect, is pronounced. As the soils forming under free drainage grade to progressively more shallow ones, as in areas peripheral to rock outcrops or where the mineral substrate changes into one of unusually coarse texture, the Upland Meadow communities have less total coverage and harbour more xeric species. This trend ultimately replaces the Meadow types with Barrens types, with less than half the surface covered. Given the soil profile and the general location on the Alaskan Arctic Slope, it is possible to predict the vegetation type with a fair degree of reliability.

On soils formed under restricted drainage a somewhat more difficult problem of soils and vegetation relationships exists. Field observations show without question that on tundra and bog soils a spectrum of plant communities exists that ranges from those dominated by species associated with well-drained sites to those dominated by species associated with very wet sites (Fig. 7) (Cantlon and Gillis, 1957). Thus, on that portion of the catena occupied by the tundra and bog soils the reliability of predicting plant-soil relationship is poorer.

To help illustrate this situation, we may compare it with better-known vegetation-soil relationships. We find that in the moist temperate region natural vegetation is useful in inferring the stages of drainage in the soil catena. It must be remembered, however, that such correlation is used for the most part with mineral soils, and very little work has been done with the vegetation differences on various organic soils. With organic soils in arctic Alaska, local differences in moisture levels produce differences in vegetation. This is true in a lower degree in the more rainy temperate region, but the total area of the drier fragments is usually insignificant. Further, in the temperate region the presence of forest lends a more homogeneous appearance, the tree layer more or less completely subjugating any micro-patterning in the understory. In the treeless Arctic, where various cryopedologic processes operate to give pronounced micro-relief, vast areas of tundra and bog soils exhibit patterns or mosaics of vegetation (Spetzman, 1951; Wiggins, 1951; Sigafoos, 1952; Churchill, 1955;

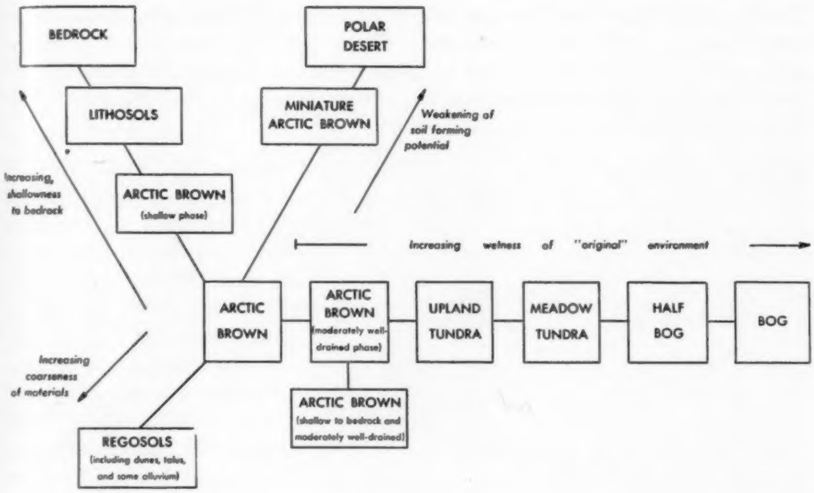

Fig. 6. The genetic soils of arctic Alaska can be arranged in the form of a sequence starting with the arctic brown and progressing through more poorly drained conditions to the bog soils. A sequence of soils is also present in the more shallow areas beginning with the arctic brown and continuing through progressively shallower soils to situations where bedrock is exposed at the surface. North of the arctic brown climatic optimum the soil process weakens and the solum becomes very shallow. Eventually the process reaches the "near zero potential" in the polar desert. When the mineral material becomes very coarse a normal profile may fail to develop, in which case the soil is included with Regosols.

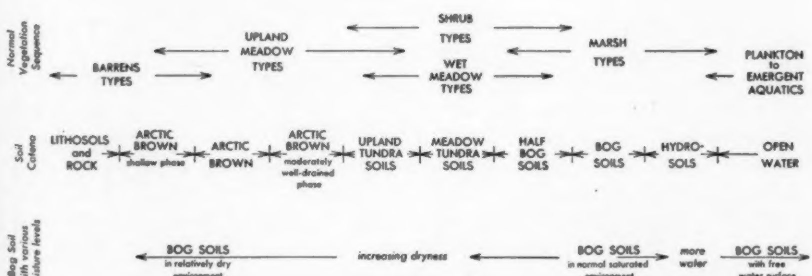

Fig. 7. Vegetation-soil relationships along a moisture gradient ranging from standing water on the right to extreme dry on the left. The soil drainage catena is in the middle row, whereas the same moisture gradient with bog soil is below. The species composition of the various vegetation types varies markedly with the moisture content of the bog soil. The shrub types and the Wet Meadow types occupy approximately the same range along the moisture gradient, the determining factors being snow depth, exposure to wind, soil aeration, summer temperatures, and others.

Drury, 1956; Bliss and Cantlon, 1957; Cantlon and Gillis, 1957; Churchill and Hanson, 1958; among others). These patterns are due to several classes of micro-site differences but soil moisture during the growing season, and snow depth during the winter are the most frequent and conspicuous differences.

Non-correspondence of profile morphology and present site conditions. In arctic Alaska bog soils normally form under naturally poor drainage, and the usual vegetation is Marsh (*Carex aquatilis*[1], *C. rotundata, C. rariflora, Carex* spp., *Eriophorum angustifolium, E. scheuchzeri, Arctophila fulva, Dupontia fisheri, Hypnum* spp., and *Sphagnum* spp., among others) or certain Meadow types (*Sphagnum* spp., *Dicranum elongatum,* and *Aulocomnium,* with *Eriophorum vaginatum, Vaccinium vitis-idaea* ssp. *minus,* and *Rubus chamaemorus,* among many others). Subsequent frost or geomorphic processes (polygonization, headward stream erosion, and lake drainage) may produce micro-relief features that in turn increase runoff and effectively reduce the moisture content of the upper soil layers (Fig. 8). On these better-drained bog soils vegetation becomes established that resembles communities normally found farther up the drainage catena. These are various Meadow types, ranging from Wet Meadow (*Eriophorum vaginatum* ssp. *spissum, Carex bigelowii, Dicranum* spp., *Aulocomnium* spp., *Salix pulchra, Vaccinium vitis-idaea* ssp. *minus, Betula nana* ssp. *exilis, Ledum palustre* ssp. *decumbens, Cetraria* spp., *Cladonia* spp., among others) to Dry Meadow (*Dryas integrifolia, D. octopetala, Vaccinium vitis-idaea* ssp. *minus, Salix phlebophylla,* and crustose lichens, among others). The more effective the drainage, the more pronounced the shift toward Dry Meadow, or on extreme convexities even to Barrens types with a sparse cover of lichens, mosses, *Luzula confusa,* and others. These latter communities may have many species in common with vegetation types normally associated with the well-drained mineral soils.

The creation of micro-relief features is somewhat analogous to the draining of bogs in more southerly areas by ditching or tile drains. In the temperate climates, however, profiles classed as well-drained usually have good drainage to a depth of 3 feet or more. The mesic species of the Arctic do not require such a great depth of well-drained soil, and adequate drainage and aeration to a depth of only a few inches is here sufficient to allow the more mesic communities of the Arctic to become established. The low rainfall, coupled with higher air speeds at ground level, favours xeric species on the pronounced convexities. These species are probably also favoured by the shallowness of the snow cover.

Just as there are conditions under which certain tundra and bog soils may exist in comparatively well-drained environments, so there are other conditions in which these soils, as based on profile morphology, appear to be in unusually wet environments (Fig. 9). It is not uncommon for a mineral soil to be completely covered with water throughout the growing season, a

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[1] Vascular plant nomenclature follows Hultén (1941-50).

Figs. 8 and 9. Bog soils in two highly diverse environments near Barrow, Alaska.

Fig. 8. Bog soil in a relatively well-drained environment. The vegetation is Upland Meadow and probably includes the mosses *Ceratodon* and *Distichium*, the lichens *Cetraria* spp., *Cladonia* spp., *Stereocaulon* and *Thamnolia vermicularis* and the vascular plants *Luzula* spp., *Poa arctica*, *Vaccinium vitis-idaea*, *Salix rotundifolia*, and *Potentilla emarginata*.

Fig. 9. Bog soil with Marsh vegetation consisting primarily of *Arctophila fulva*, *Eriophorum* spp., *Carex aquatilis* and *Dupontia fisheri*. The mosses *Tomethypnum* and *Drepanocladus* are also present. Unless the relative wetness of the site is considered, these two soil conditions (Fig. 8 and Fig. 9) would probably be classed as the same unit.

condition favourable to the eventual formation of an organic soil. Apparently, this situation arises from formation of low-centre polygons, frost collapse, frost action in the soil, the element of time, and related factors, that cause a change in environment. Because of the short, cool growing season, however, organic matter accumulates at a very slow rate (Warren Wilson, 1957). Other situations in which the soils may be in a wetter environment than the profiles suggest are those where subsidence from thermokarst activity (Wallace, 1948; Hopkins, 1949) or stream meandering have occurred.

Normally the morphology of the soil profile is an expression of the combined factors of soil formation. If the environment changes, then the morphology should also change. Apparently, readjustment to the new environment takes place so slowly under arctic conditions that the higher water content of these mineral soils or the well-drained surface on bog soils are "semi-permanent" features of the profiles. Such lack of correspondence between the profile and present environment occurs widely and no better suggestion for their interpretation is at hand.

Soil variation and soil mapping problems. Drew (1957) discussed some of the problems involved and prepared a map of the soils of the Barrow area in northern Alaska. In flat, highly polygonized areas (Fig. 10), a high order of variation in micro-relief features influences the moisture content of the surface soil. The elevated portions of the polygons are comparatively dry, whereas the low portions of the polygonized areas are commonly covered with water during the summer months. Thus, within distances of a few feet, a wide spectrum of soil conditions and plant species is commonly found (Wiggins, 1951). In the highly polygonized areas it would be virtually impossible to delineate and describe even in broadest terms a profile *per se* unless an abnormally large scale was used.

Somewhat akin to the difficulties met with on poorly drained sites are those frequently encountered on the steeply sloping uplands. Here, although non-sorted polygons (Washburn, 1956) are feebly expressed and perhaps locally absent, another type of micro-topography occurs. This takes the form of small, oblong mounds, ranging from a few inches up to 2 feet in height and from 2 to 6 feet long, with their long axes frequently at right angles to the contour. Irregular trenches occur between, the width of which varies from a few inches to a few feet. The soil in the trenches has a somewhat thicker organic layer and is moist, whereas the convexities have a slightly thinner layer and are drier. If slope is not excessive the differences between the mounds and the trenches are small and the entire complex falls within the range of what can be classed as upland tundra or meadow tundra soils. The vegetation on the two kinds of micro-sites show a marked difference, however, giving rise to an intricate mosaic composed of two or more groups of species (basic units in the sense of Hopkins, 1957), but which in descriptions are lumped into one "community".

On steeper slopes the micro-relief is more pronounced and the differences in vegetation between convexities and trenches strain the single "community" designation. The soil, with its excessive number of mounds

Fig. 10.

Fig. 11.

Figs. 10 and 11. Soil classification is more complicated in areas of polygonization than in the sloping areas of smooth relief. Fig. 10 shows a highly polygonized soil near Point Barrow. Fig. 11 shows rather smooth terrain features in the uplands near Umiat.

and solifluction lobes, also may exceed the range usually recognized in upland or meadow tundra soils. These soils, together with such local variants as extensive areas of frost boils and stone nets, might be given special status in the delineated soil unit nearest to it in the drainage catena.

The authors believe that the soils in the arctic regions can be classified in somewhat the same manner as they are being classified in other climatic regions. In fact, delineating soil units on the well-drained sites in the Arctic is little different from doing so on their temperate region counterparts. The areas are large enough and vegetation types have a fair degree of indicator value on these sites. Delineating tundra soils on gently to steeply sloping areas, such as in Fig. 11, can be done with facility, although there is some irregularity in the profile morphology. However, on the steep solifluction slopes (Fig. 2) and on the flat, highly polygonized areas factors in addition to profile morphology should be considered. Perhaps the independent mapping of micro-relief characteristics as proposed by Drew (1957) would suffice. Another alternative would be to describe the pattern of the soil complex based on principles set forth by Veatch (1934).

Summary

The soils of arctic Alaska can be arranged in a drainage catena in the same manner as those of other climatic regions. Mature or zonal soils (arctic brown) may be said to form only under adequate internal drainage. Tundra soils would thus not be considered mature or zonal, instead they would be intrazonal (hydromorphic). The arctic brown and related soils with brown surface horizons, tundra soils, and bog with permafrost are northern extensions or counterparts of podzol, humic glei, and bog soils, respectively.

Plant communities have been successfully correlated with soils on well-drained sites and on areas of shallow soils. Correlation between soils and vegetation on the tundra and bog soils, however, poses major problems. Non-correspondence of soil profile with current site conditions is widespread because of the lag in development processes. Vegetation reflects the changes somewhat earlier. If relative wetness of the site is considered together with the profile morphology a workable relationship between soils and plant communities generally exists; and if the nature of the cryopedologic features is mapped independently, suitable soil maps may be prepared.

Appreciation is expressed to R. B. Alderfer, F. E. Bear, F. H. Bormann, L. A. Douglas, J. V. Drew, J. J. Koranda, and R. E. Shanks, for important field discussions and critical examination of the manuscript. The earlier phases of our arctic investigations were supported by Boston University, Physical Research Laboratory.

These studies were aided by a contract between ONR, Department of the Navy, and the Arctic Institute of North America. Reproduction in whole or in part is permitted for any purpose of the United States government.

References

Bliss, L. C. and J. E. Cantlon. 1957. Succession on river alluvium in northern Alaska. Am. Midl. Nat. 58:452-69.

Cantlon, J. E. and W. T. Gillis. 1957. Arctic plants in relation to various relief features. Bull. Ecol. Soc. Am. 38:98-9. (Abstract of unpublished paper presented at A.A.A.S. meeting, Indianapolis, Dec., 1957.)

Churchill, E. D. 1955. Phytosociological and environmental characteristics of plant communities in the Umiat region of Alaska. Ecology 36:606-27.

Churchill, E. D. and H. C. Hanson. 1958. The concept of climax in arctic and alpine vegetation. Bot. Rev. 24:127-91.

Drew, J. V. 1957. A pedologic study of arctic Coastal Plain soils near Point Barrow, Alaska. Unpublished Ph.D. Thesis, Rutgers University.

Drew, J. V. and J. C. F. Tedrow. 1957. Pedology of an arctic brown profile near Point Barrow, Alaska. Soil Sci. Soc. Am. Proc. 21:336-9.

Drury, Jr., W. H. 1956. Bog flats and physiographic processes in the upper Kuskokwim River region, Alaska. Contr. Gray Herb., Harvard Univ. 178:1-130.

Glinka, K. D. 1928. The great soil groups of the world and their development. (Translated by C. F. Marbut) Ann Arbor: Edwards Bros. pp. 235.

Gorodkov, B. N. 1939. Peculiarities of the arctic top soil. Isvestiya Gosudarstvennogo Geograficheskogo obshchestva 71 (10):1516-32.

Kellogg, C. E. and I. J. Nygard. 1951. Exploratory study of the principal soil groups of Alaska. U.S. Dept. Agr. Agricultural Monograph 7. pp. 138.

Hopkins, B. 1957. Pattern in the plant community. J. Ecol. 45:451-63.

Hopkins, D. M. 1949. Thaw lakes and thaw sinks in the Imuruk Lake area, Seward Peninsula, Alaska. J. Geol. 57:119-31.

Hultén, E. 1941-50. Flora of Alaska and Yukon, Parts I-X. Lunds Universitets Årsskrift, N.F., Vols. 37-46.

Leahey, A. 1949. Factors affecting the extent of arable lands and the nature of the soils in the Yukon Territory. Proc. 7th Pacific Sci. Congr. 6:16-20.

Marbut, C. F. 1927. A scheme for soil classification. Proc. 1st Int. Congr. Soil Sci. V. 4 Comm. V:1-31.

Margulis, H. 1954. Aux sources de la pédologie. Publication de l'école nationale supérieure agronomique de Toulouse, pp. 85.

Meinardus, W. 1930. Boden der kalten Region. *In* E. Blank (Editor) Handbuch der Bodenlehre. Vol. 3, pp. 550. Berlin: J. Springer.

Neustruev, S. S. 1927. Genesis of soils. Russian pedological investigations, Acad. of Sci. U.S.S.R., Leningrad, 1-98.

Robinson, G. W. 1949. Soils, their origin, constitution and classification. pp. 573. London: Thomas Murby and Co.

Sigafoos, R. S. 1952. Frost action as a primary physical factor in tundra plant communities. Ecology 33:480-7.

Sigafoos, R. D. and D. M. Hopkins. 1952. Soil instability on slopes in regions of perennially frozen ground. Frost action in soils: a Symposium. Highw. Res. B. Spec. Rep. 2, Natl. Res. Counc. Publ. 213, pp. 176-92.

Spetzman, L. A. 1951. Plant geography and ecology of the arctic slope of Alaska. Unpublished M.Sc. Thesis, Univ. of Minnesota.

Tedrow, J. C. F., J. V. Drew, D. E. Hill, and L. A. Douglas. 1958. Major genetic soils of the arctic slope of Alaska. J. Soil Sci. 9:33-45.

Tedrow, J. C. F. and D. E. Hill. 1955. Arctic brown soil. Soil Sci. 80:265-75.

Veatch, J. C. 1934. Classification of land on a geographic basis. Michigan Acad. of Sci., Arts, and Letters. Vol. 19:359-65.

Wallace, R. E. 1948. Cave-in lakes in the Nabesna, Chisana and Tanana river valleys, eastern Alaska. J. Geol. 56:171-81.

Warren Wilson J. 1957. Observations on the temperatures of arctic plants and their environment. J. Ecol. 45:499-531.

Washburn, A. L. 1956. Classification of patterned ground and review of suggested origins. Bull. Geol. Soc. Am. 87:823-66.

Wiggins, I. L. 1951. The distribution of vascular plants of polygonal ground near Point Barrow, Alaska. Contr. Dudley Herb., Nat. Hist. Mus., Stanford Univ., Calif. 4:41-56.

SEED GERMINATION IN ARCTIC AND ALPINE SPECIES

L. C. Bliss*

Arctic and alpine species today occupy large areas that only a few thousand years ago were covered by great ice sheets or the sea. Not all arctic land areas were glaciated, however, for refugia such as Beringia, the coast of northern Alaska, the Yukon valley, and a part of the Arctic Archipelago remained free of ice and there many species were able to survive, rather than suffer extinction or be forced by the advancing ice to migrate south (Hultén, 1937). Although the numbers of biotypes (or strains) of many species were reduced and thus the adaptability of these species impaired by the considerable climatic changes caused by the alternation of warm and dry interglacial and cold glacial periods, many retained the capacity to recolonize their former habitats after the ice had finally retreated. This recolonization is the result of both vegetative reproduction by bulblets, runners, rhizomes, etc., and dispersal by seeds.

The present study was undertaken to give a better understanding of seed viability of both arctic and alpine species; for field observations indicate that seedlings are not numerous, especially in the Arctic. Nomenclature follows that of Hultén (1941-50) for the arctic species and Harrington (1954) for the alpine species. Appreciative acknowledgement is made to the Department of Botany, Duke University, where the germination tests were made and to Boston Physical Research Laboratories under the auspices of which the Alaskan work was carried out.

An extensive study of flower development and seed germination of arctic-alpine species has been made by Söyrinki (1938-9) in Petsamo-Lappland. Of 91 species tested 79 germinated. Sørensen (1941) ran germination tests on the seeds of 99 species in northeast Greenland, in which those of 62 species germinated. Nearly one half of those that failed to germinate belonged to the Cyperaceae (sedge family). He found that germination occurred even though the seeds remained frozen for almost half of each 24-hour period. Seed production by arctic and alpine species has been discussed by A. E. Porsild (1920), M. P. Porsild (1920), Holttum (1922), and Böcher (1949); and seed dispersal mechanisms by Holm (1922) and Porsild (1951). Growth rates and survival of seedlings in Greenland were studied by Wager (1938). Stoeckeler (1949) reported that arctic willow seeds require a mineral substrate for germination, whereas seeds of alder and birch germinate on peat.

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Nichols (1934) ran germination tests on seeds of 19 alpine species from the White Mountains, New Hampshire. These showed that without refrigeration germination was considerably reduced in 14 of the 19 species. Pelton (1956) found that of 18 species from Colorado, collected in the subalpine zone, alpine bistort (*Polygonum viviparum*) and trisetum (*Trisetum spicatum*) seeds did not require dormancy. Holch *et al.* (1941) reported that rhizomes provide the best means of propagation of alpine plants in the Rocky Mountain Park. They stated (p. 339) ". . . the short growing season results either in the production of no seed or of small amounts of seed of low vitality."

The germination studies reported here were made on 36 arctic and 26 alpine species. Seeds of the arctic species were collected directly from plants in and near Umiat, Alaska, 69°22'N. 152°10'W., 350 feet above sea-level, in August 1953. Northern Alaska, including Umiat, is designated as "low arctic" by Polunin (1951) in contrast to the climatically more severe and floristically poor "high arctic" farther north. This low arctic region is characterized by extensive sedge marshes, lichen-rich heaths, and shrub communities 1 metre or more in height in sheltered places. Some of the arctic species reported here range from boreal to low arctic regions, whereas others range from low to high arctic regions. The species are so marked in Table 1. Seeds of the alpine species were obtained from plants growing in the alpine tundra of the Snowy Range of the Medicine Bow Mountains, 41°20'N. 106°19'W., 11,000 feet above sea-level, approximately 40 miles west of Laramie, Wyoming, in 1954 and 1955. Seeds were placed in glass vials or paper bags, air dried and shipped to Duke University, where they were stored at 5°F. for 6 to 7 months. After removal from storage, the seeds were cleaned, sorted and the unfilled and shrunken ones removed. Seeds from fleshy fruits were separated before testing. Duplicate samples of untreated seeds were placed in sterilized Petri dishes between layers of moist filter paper and incubated at 72°F., one sample in the light and the other in the dark. Distilled water was added when necessary to keep the filter paper moist. The dishes were removed twice a week for seed counting, at which time the continuous dark period was broken for approximately 1 hour. The number of seeds tested varied according to the quantity of seed available. Seeds were considered to have germinated when the radicle appeared.

The data in Table 1 show that of the 36 arctic species only 22 species or 61 per cent and of the 26 alpine species 21 or 80 per cent germinated. Arctic species that did not germinate included 5 ericaceous species, 3 each of willow (*Salix*) and lousewort (*Pedicularis*), also buckbean (*Menyanthes trifoliata*), Lapland buttercup (*Ranunculus lapponicus*), and cloudberry (*Rubus chamaemorus*). Alpine species not germinating included 2 species of willow (*Salix*) and 3 of sedge (*Carex*).

No great differences were found between the average germination percentages of the various species from the two tundras. Thus 13 of the 22 arctic species and 10 of the 21 alpine species germinated at the 50 per cent level or better. Eleven of the 22 arctic species that germinated in the light

showed a significant change[1] in germination percentage when kept dark; 10 species showed a reduction and 1 an increase in percentage. Only 6 of the 21 alpine species that germinated in the light were significantly affected by continuous darkness; germination percentages were reduced in 5 and increased in 1 species. None of the arctic or alpine species germinated exclusively in the dark, but 9 of the 43 did so only in the light.

All arctic species tested that were usually found growing on deeply thawed soil, with the exception of feltleaf willow (*Salix alaxensis*), germinated in both light and darkness, in contrast to those arctic species that

Table 1. Germination percentages for arctic and alpine species. The data include minimum, mean, and maximum germination time in days. Range of the arctic species is shown as follows: B = boreal, LA = low arctic, HA = high arctic.

		Germination					
		in the light			in the dark		
Species	**Range**	number tested	per cent	time days	number tested	per cent	time days
Arctic species							
Common on deeply thawed soils							
Erigeron purpuratus	LA	47	100.0	4 - 4-11	72	100.0	4 - 6-11
Crepis nana	B-HA	114	97.4	3 - 3 - 6	65	98.5	3 - 3-10
Epilobium latifolium	B-HA	72	94.5	7 - 7-11	55	91.0	3 - 7-11
Parnassia palustris	B-LA	109	86.0	7 - 7-10	188	85.2	7 - 7-10
Lupinus arcticus	B-LA	79	75.1	6-10-19	59	63.4	3 - 3-14
Aster sibiricus	B-LA	32	56.3	4-11-21	58	50.0	4 - 7-21
Astragalus alpinus	B-HA	86	39.5	4 - 7-19	34	59.0†	4 - 7-19
Papaver radicatum	LA-HA	1054	23.0	7-10-24	454	5.4*	7 - 7-14
Senecio congestus	B-HA	136	21.0	3 - 3 - 7	132	4.5*	3 - 3 - 3
Oxytropis sp.	——	39	18.0	4 - 7 - 7	39	18.0	4 - 7-14
Salix alaxensis	B-LA	154	0.0	0 - 0 - 0	120	0.0	0 - 0 - 0
Common on shallowly thawed soils							
Petasites frigidus	B-HA	80	96.0	3 - 3-14	84	87.0†	3 - 7-21
Arctagrostis latifolia	B-HA	44	80.0	7-14-21	42	9.6*	7-14-21
Dryas integrifolia	B-HA	52	67.0	7 - 7-35	36	81.0	10-14-28
Cassiope tetragona	LA-HA	293	52.0	7-21-26	177	0.0*	0 - 0 - 0
Betula nana exilis	LA	54	52.0	3 - 3-13	43	38.2	6 - 6-17
Ledum palustre decumbens	B-LA	1273	51.2	10-13-25	531	0.0*	0 - 0 - 0
Saxifraga punctata nelsoniana	B-LA	283	37.5	6-17-25	297	0.0*	0 - 0 - 0
Eriophorum vaginatum spissum	B-LA	479	22.6	7-10-35	286	0.0*	0 - 0 - 0
Alnus crispa	B-LA	100	15.0	3 - 6-13	66	2.3*	17-17-17
Carex bigelowii	B-HA	288	6.2	10-10-10	149	0.0†	0 - 0 - 0
Carex aquatilis	B-HA	147	2.7	6 - 6-10	94	0.0	0 - 0 - 0
Eriophorum angustifolium	B-LA	338	0.9	3 - 3-10	332	1.2	10-10-17
Andromeda polifolia	B-LA	90	0.0	0 - 0 - 0	62	0.0	0 - 0 - 0
Arctostaphylos alpina	B-LA	39	0.0	0 - 0 - 0	30	0.0	0 - 0 - 0
Empetrum nigrum	B-HA	67	0.0	0 - 0 - 0	61	0.0	0 - 0 - 0
Menyanthes trifoliata	B-LA	63	0.0	0 - 0 - 0	49	0.0	0 - 0 - 0
Pedicularis capitata	B-HA	74	0.0	0 - 0 - 0	73	0.0	0 - 0 - 0
Pedicularis labradorica	B-LA	57	0.0	0 - 0 - 0	52	0.0	0 - 0 - 0
Pedicularis lanata	B-HA	58	0.0	0 - 0 - 0	77	0.0	0 - 0 - 0
Ranunculus lapponicus	B-LA	135	0.0	0 - 0 - 0	138	0.0	0 - 0 - 0
Rubus chamaemorus	B-LA	50	0.0	0 - 0 - 0	57	0.0	0 - 0 - 0
Salix arbusculoides	B-LA	116	0.0	0 - 0 - 0	104	0.0	0 - 0 - 0
Salix pulchra	B-LA	140	0.0	0 - 0 - 0	110	0.0	0 - 0 - 0
Vaccinium uliginosum	B-HA	98	0.0	0 - 0 - 0	102	0.0	0 - 0 - 0
Vaccinium vitis-idaea minus	B-LA	136	0.0	0 - 0 - 0	112	0.0	0 - 0 - 0

[1] Statistical analysis based on the standard error of the difference test.

		Alpine species				
Androsace septentrionalis	35	100.0	5 - 8 - 8	37	100.0	5 - 5 - 5
Hymenoxys grandiflora	149	100.0	5 - 5-19	185	98.0	5 - 5-12
Artemisia scopulorum	22	100.0	5-12-12	24	92.0	5-12-19
Arenaria obtusiloba	24	100.0	5 - 5-12	27	85.0	5 - 5-15
Geum turbinatum	38	100.0	5 - 5-29	41	78.0*	8-12-23
Erigeron pinnatisectus	128	98.0	5 - 5-15	132	96.5	5 - 5-12
Silene acaulis	239	86.7	5 - 5-26	191	89.7	5 - 5-26
Phleum alpinum	144	86.6	8-15-40	92	76.0†	12-12-33
Poa alpina	117	85.5	8 - 8-22	68	91.2	5 - 8-26
Trisetum spicatum	46	54.3	8-12-40	39	77.1†	8-15-22
Sibbaldia procumbens	76	44.0	5 - 8-19	44	43.3	5 - 5-22
Trifolium dasyphyllum	35	37.1	5 - 5-40	41	46.4	5 - 5-33
Salix brachycarpa	127	27.5	7-11-25	109	23.0	7-11-25
Kalmia polifolia microphylla	73	24.6	12-22-40	90	0.0*	0 - 0 - 0
Oxytropis campestris glabrata	88	21.2	4 - 4-25	148	22.3	4-11-32
Polygonum bistortoides	73	19.2	14-18-32	92	3.2*	11-21-21
Draba crassifolia	81	11.1	8 - 8-26	65	0.0†	0 - 0 - 0
Potentilla diversifolia	19	10.5	12-12-12	24	8.3	5 - 8 - 8
Polygonum viviparum	76	4.0	14-14-18	127	9.5	11-11-21
Polemonium viscosum	109	2.8	5 - 8 - 8	88	0.0	0 - 0 - 0
Pedicularis parryi	84	1.2	5 - 5 - 5	114	2.9	8 - 8 - 8
Carex aquatilis	43	0.0	0 - 0 - 0	52	0.0	0 - 0 - 0
Carex drummondiana	34	0.0	0 - 0 - 0	41	0.0	0 - 0 - 0
Carex scopulorum	56	0.0	0 - 0 - 0	67	0.0	0 - 0 - 0
Salix cascadensis	62	0.0	0 - 0 - 0	84	0.0	0 - 0 - 0
Salix planifolia monica	87	0.0	0 - 0 - 0	80	0.0	0 - 0 - 0

† Significant difference at the 5 per cent level.
* Significant difference at the 1 per cent level.

most frequently occurred on the wet tundra soils that thawed only shallowly. Only 48 per cent of the last group germinated under both conditions; some with only very low percentages.

Among the arctic species, white heather *(Cassiope tetragona)* and Labrador tea (*Ledum palustre* ssp. *decumbens*) had 50 per cent germination in the light and no germination in the dark. Germination of the grass *Arctagrostis latifolia* and the saxifrage *Saxifraga punctata* ssp. *nelsoniana* was reduced in the dark by 70 and 37.5 per cent respectively. Cotton-grass (*Eriophorum vaginatum* ssp. *spissum*) seeds did not germinate in the dark, yet when the same seeds were placed in constant illumination 22 per cent of them germinated, which was about the same percentage as that for the seeds placed into the light immediately (23 per cent). This species was the only one to show this behaviour.

The alpine species in which germination in the dark was reduced by at least 20 per cent included an avens (*Geum turbinatum*) and bog laurel (*Kalmia polifolia* ssp. *microphylla*); in contrast germination in *Trisetum spicatum* increased by 23 per cent in the dark. Seeds of most alpine species showed no significant reduction of germination in continuous darkness.

Many seedlings of the willow *Salix planifolia* var. *monica* were found in the field in late July after seed dispersal. Since seeds failed to germinate after 7 months of storage, field germination tests were made to determine the duration of seed viability. Freshly collected, air-dried seeds were used in 1955 and between 500 and 1,000 were tested each week. The results show that germination was at first very high (94 per cent), but it had dropped

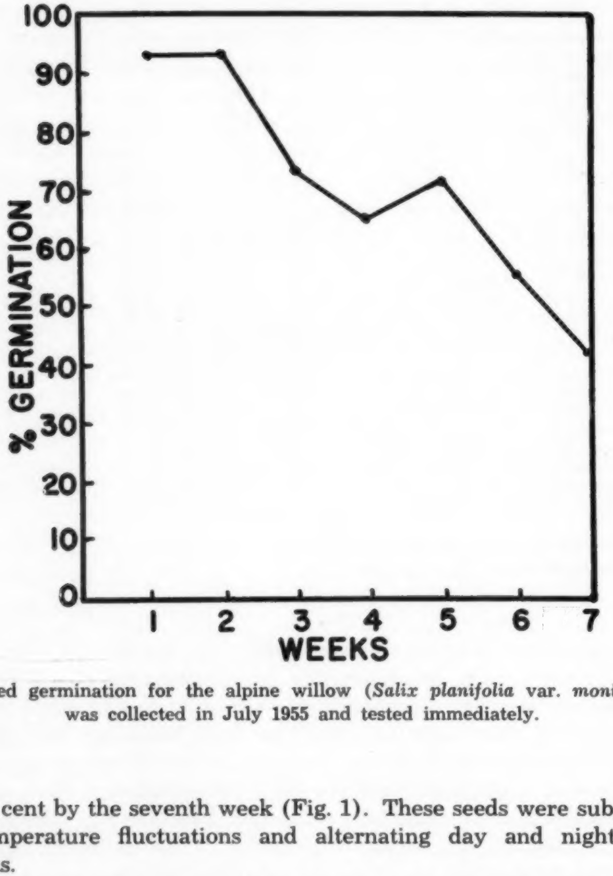

Fig. 1. Seed germination for the alpine willow (*Salix planifolia* var. *monica*). Seed was collected in July 1955 and tested immediately.

to 42 per cent by the seventh week (Fig. 1). These seeds were subjected to daily temperature fluctuations and alternating day and night in the mountains.

Although all data presented in Table 1 are the results of germination tests carried out with seeds that had been frozen for from 6 to 7 months, a few of the arctic seeds germinated after having been stored for 30 months. Of those tested after this period of storage, alder (*Alnus crispa*), birch (*Betula nana* ssp. *exilis*), cotton-grass (*Eriophorum vaginatum* ssp. *spissum*), and sedge (*Carex aquatilis*) had germination percentages that were comparable to those reported above. How long these seeds will remain viable is not yet known.

A small percentage of the seeds of *Carex aquatilis* collected in Alaska germinated, but none from the alpine tundra. Although no data are included for arctic seeds of *Polygonum viviparum* and *Trisetum spicatum*, seeds of these two species were collected and tested at a later date. The results showed that both produce viable seed in the two tundras, but germination percentages for both were somewhat higher for the arctic than for the alpine seeds.

The failure of the seed of some species to germinate should not be interpreted as an indication of non-viability, because the conditions essential for germination may not have been provided. These could be in the form of lower temperatures, alternating temperatures, differences in photoperiod, or scarification.

The data of Table 1 suggest that the arctic species are divided into two habitat groups according to whether the germination of their seeds is significantly reduced in the dark or not, i.e., those species of which the seeds germinate equally well in the light and in the dark grow commonly on the deeply thawed soils of river bottoms, flood plains, steep slopes, dry ridge tops, and the raised rims of polygons; whereas those species in which the seeds do not germinate in the dark or only in small proportions grow generally in upland, wet tundra soils that thaw only shallowly. The former (non-light-sensitive) germination pattern is also typical of the alpine species tested.

Ecologically these reactions to light and dark treatment can be explained in several ways. The arctic species with seeds that germinate equally well in light and darkness frequently grow where the seeds are subject to burial by spring flooding with the resultant accumulation of sand and silt (Bliss and Cantlon, 1957), as opposed to the light-sensitive species usually found in upland tundra areas, the seeds of which become rarely buried because of the slow rate of accumulation of organic matter. On the other hand, burial of seeds of both arctic and alpine species could result from wind-blown sand or silt.

Another possibility is that the significantly higher germination in the light in the species common to wet, shallowly thawed soils is influenced by longer photoperiods. In the alpine species tested and those arctic ones commonly found on deeply thawed soils, the seeds of which germinate equally well in light and darkness, germination is enhanced by shorter photoperiods. The data presented here are insufficient to support any conclusions as to the causes of this division into habitat groups of species according to germination differences.

Soil-surface temperatures at Umiat ranged from 31° to 92°F. with monthly means between 45° and 54°F. in 1953. Surface and soil temperatures were somewhat higher on steep slopes and river-gravel areas. Alpine soil-surface temperatures ranged from 33° to 97°F. in 1954 and 1955, with monthly means between 46° and 62°F. (Bliss, 1956). The tundra soils were thus quite favourable for germination in terms of temperature during the growing season, for Sørensen (1941) has pointed out that many arctic seeds germinated in Greenland when temperatures were above the freezing point for only about one half of each 24-hour period.

Seeds of *Salix brachycarpa* remained viable in storage for a longer period than those of *S. planifolia* var. *monica*. Since seeds of the former species ripen in late August, whereas those of the latter ripen by the end of July, it would appear that seeds of *S. brachycarpa* are better able to overwinter and germinate in the spring. Söyrinki (1938-9) believed that

some species of Lapland willows were capable of germination after overwintering. Germination tests and field observations showed that seeds of *Salix planifolia* var. *monica* germinated immediately after dispersal and that their viability decreased rapidly. Seedling establishment in this species thus usually occurs in the same season as seed production.

Field observations tend to confirm the results of the germination tests on the arctic species. Seedlings were quite common on the deeply thawed soils, especially on the sands and silts of flood plains. Dormancy was broken in seed from all species occupying these habitats, except the willows. In contrast, many of the species that typically grow in the wet tundra soils that thaw only shallowly, appear to reproduce mainly by vegetative means, for seedlings were difficult to find. These observations corroborate the germination tests in which dormancy was broken in the seeds of only 13 of the 25 species that commonly grow in the wet tundra soils. In the alpine tundra seedlings of many species were found; this indicates that reproduction through seed occurs in addition to vegetative propagation. Seeds of 80.7 per cent of the species germinated.

Numerous species that flowered abundantly and set considerable amounts of seed at Umiat flowered much less intensively and set little, if any, seed on the Coastal Plain in 1953 (Bliss, 1956). The Coastal Plain is less favourable for plant development than the Umiat area in terms of microenvironments. Similar observations were made in the alpine tundra, where plant height, flowering, and seed production, were reduced in those species growing on an exposed ridge as opposed to the same species growing in more favourable microenvironments on both north- and south-facing slopes. Thus local variations in flowering and fruiting as the result of habitat extremes may be as great as over large geographical areas.

These data concerning apparent habitat preferences as well as germination percentages in light and dark chambers should not be interpreted as being characteristic of these species in other tundra regions. Some of the species that flower and fruit abundantly in low and mid arctic regions seldom flower or set fruit in the High Arctic. Of necessity vegetative propagation is most important there. Habitat preferences of some species may also change from northern Alaska to northern Greenland and Ellesmere Island.

Summary

Germination tests on seeds collected in the arctic tundra of northern Alaska and the alpine tundra of southeastern Wyoming indicate that viable seed is produced by many species in each region. Seeds of a greater proportion of alpine than of arctic species germinated, although high percentages of germination were found in individual species from both tundras. The results of the germination tests carried out in light and darkness on the various arctic plants correlate quite well with differences in their general habitats. Most species that are usually found on deeply thawed

soils (flood plains, steep slopes, and dry ridges) produce seeds, which germinate equally well in the light and in the dark. Viable seeds were found in 91 per cent of these species. The seeds of nearly all the species most frequently found in the wet tundra soils that thaw only shallowly had significantly lower germination percentages in the dark. Even in the light only 48 per cent of the seeds of these species germinated, and 76 per cent did not germinate at all in the dark. There is no indication of habitat segregation of the alpine plants based on germination in the light and the dark, although reduced rates of germination in the dark were recorded in some species.

It is suggested that the arctic and alpine species that produce seeds that germinate equally well in the light and the dark are species the seeds of which are subject to being buried, or are species the seeds of which are not light sensitive. The species in which germination is significantly reduced in the dark may be light sensitive. Length of photoperiod may also play a role in these differences in germination.

Seeds of the alpine willow *(Salix brachycarpa)* remain viable over winter and in nature probably germinate in the spring. This species does not mature its seeds until late August. *Salix planifolia* var. *monica*, however, matures its seeds in July and the seeds can germinate immediately. Germination tests indicated that viability is seldom, if ever, retained over winter in this species. Seedling establishment probably occurs during the same season in which the seeds are produced.

These results corroborate field observations that seedlings of arctic species are more abundant for those plants that grow on deeply thawed soils. Vegetative propagation is the most important means of reproduction in many of the species restricted to shallowly thawed soils in the upland tundra. The germination data for alpine species substantiate the field observations that seedlings are quite common, although vegetative propagation is also of great importance.

Generalizations based on this study should only be made regarding the germination pattern and habitat preferences of these species in the areas discussed, because the species may vary considerably elsewhere throughout the tundra regions.

References

Bliss, L. C. 1956. A comparison of plant development in microenvironments of arctic and alpine tundras. Ecol. Monogr. 26:303-37.

Bliss, L. C. and J. E. Cantlon. 1957. Succession on river alluvium in northern Alaska. Am. Midl. Nat. 58:452-69.

Böcher, T. W. 1949. Climate, soil, and lakes in continental West Greenland in relation to plant life. Medd. om Grønl. 147(2):1-63.

Harrington, H. D. 1954. Manual of the plants of Colorado. Denver: Sage Books Co. 666 pp.

Hoch, A. E., E. W. Hertel, W. O. Oakes, and H. H. Whitwell. 1941. Root habits of certain plants of the foothills and alpine belts of Rocky Mountain National Park. Ecol. Monogr. 11:327-45.

Holm, T. H. 1922. Contributions to the morphology, synonymy, and geographical distribution of arctic plants. Rept. Can. Arc. Exp. 1913-18, Vol. 5, Pt. B, 139 pp.

Holttum, R. E. 1922. The vegetation of West Greenland. J. Ecol. 10:87-108.

Hultén, E. 1937. Outline of the history of arctic and boreal biota during the Quaternary period. Stockholm: Bokforlags Aktiebolaget Thule, 168 pp.

———1941-50. Flora of Alaska and Yukon. Lunds Univ. Årsskrift N.F., Vol. 37-46, 1902 pp.

Nichols, G. E. 1934. The influence of exposure to winter temperatures upon seed germination in various native American plants. Ecol. 15:364-73.

Pelton, J. 1956. A study of seed dormancy in eighteen species of high altitude Colorado plants. Butler Univ. Bot. Stud. 13:74-84.

Polunin, N. 1951. The real Arctic: suggestions for its delimination, sub-division and characterization. J. Ecol. 39:308-15.

Porsild, A. E. 1920. Sur les poids et les dimensions des grains arctiques. Revue Générale de Botanique. 32:97-120.

———1951. Plant life in the Arctic. Can. Geog. J. 42:120-45.

Porsild, M. P. 1920. Flora of Disko Island and West Greenland, from 66° — 71°N. latitude. With remarks on phytogeography, ecology, flowering, fructification, and hibernation. Medd. om Grønl. 58 (1): 1-156.

Sørensen, T. 1941. Temperature relations and phenology of the northeast Greenland flowering plants. Medd. om Grønl. 125 (9): 1-305.

Söyrinki, N. 1938-39. Studien über die generative und vegetative Vermehrung der Samenpflanzen in der alpinen Vegetation Petsamo-Lapplands I und II. Ann. Soc. Zool.-Bot. Fenn. Vanamo. 11:1-323 and 14:1-405.

Stoeckeler, E. G. 1949. Identification and evolution of Alaskan vegetation from air photos with reference to soil, moisture, and permafrost conditions. U. S. Army Corps. Eng. St. Paul, Minn. 103 pp.

Wager, H. G. 1938. Growth and survival of plants in the Arctic. J. Ecol. 26: 390-410.

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NORTHERN NEWS

Glacial-geomorphological research in the Howells Valley and the watershed district of Central Quebec-Labrador

With two field assistants, T. C. Grewar and D. H. Tarling, the writer spent the summer of 1958 expanding the work carried out in 1957 in the immediate vicinity of Knob Lake. The study area comprised the whole of the Howells Lake and River system between the southern shores of Helluva Lake (55°18'N.) and Stakit Lake (54°44'N.), the Quebec-Labrador watershed, and the neighbouring slopes of the Swampy Bay River, which joins the Koksoak-Kaniapiskau drainage farther north. The whole area, with the exception of the Shield rocks of the western slopes of the Howells Valley, is underlain by the Proterozoic sediments of the Labrador Trough.

The party was able to move out from Knob Lake by truck, using the exploration bush tracks of the Iron Ore Company of Canada. On June 22 the first base camp was established 17 miles northwest of Knob Lake on a spur overlooking Triangle Lake, Labrador. During the next 6 weeks work was conducted from this point, a sub-base having been established on the granite-gneiss

of the western slopes of the Howells Valley, and another on the sedimentary rocks at O'Nelly Lake. The second half of the season, beginning on August 5, was spent working from a base camp 1 mile east of Boundary Lake, Quebec. During this time a sub-base was established on the granite-gneiss 2 miles west of Harris Lake, and another sub-base was placed 2 miles northwest of the northern end of Lac Lespinay, which drains into the lake complex occupying the wide valley north of the town of Knob Lake and thence by way of the Swampy Bay River to Ungava Bay.

During the first half of the season, with the exception of a rain-hail-snow squall of the morning of July 1, extremely good weather prevailed, consequently, more work was accomplished than had been planned for the southern section. Despite the delays caused by 5 inches of rain, which fell in August, the field programme was completed.

Interest was centred on the widespread glacial drainage channels, which were examined in the light of the classification arrived at following the 1957 field season[1] as a means of determining both the position and condition of the wasting ice-mass. Attention was also paid to a remarkable series of delta-like forms, which are found at different elevations along the eastern slopes of the Howells system.

The distinctive appearance of the drainage channels on air photographs[2] made possible the concentration on the critical sets of channels that stretch from the highest parts of the watershed at over 2,600 feet to the bottom of the Howells Valley at 1,700 feet. The direction of flow of the marginal melt waters, which is consistently to the south in the southern section, changes to the north in the vicinity of Joan Brook. At this point marginal drainage channels with a northerly gradient are found only 1 mile from the nearest evidence of a southerly flow of melt waters. The ground in between is characterized by hummocky till and shows evidence of the subglacial escape of water to the local base level of the Howells waters.

Only minor streams now run across each of the delta features, which are clearly not of recent origin. Examination in the field revealed that the deltas, which often drop as much as 50 feet per mile, are sub-serial forms that were most probably scattered over the bedrock at a time when ice impinged upon the Howells' slopes. Their morphology, slope, and composition are incompatible with deposition in water. This fact and the presence of marginal drainage channels a few feet above the present water-levels strongly suggest that there was no late-glacial lacustrine phase in the Howells Valley. Furthermore, strong evidence of subglacial drainage is to be found from the highest cols in the watershed down to present lake level in the Howells Valley.

Fair evidence of striae was observed a 10-mile front on the western slopes of the valley and over the entire area to the east as far as the higher slopes of the Swampy Bay River system. The direction of the final movement of the ice is by no means unequivocal, although well-developed drift tails throughout the western part of the area indicate final movement from the south-southeast to north-northwest along the valley itself and parallel to the neighbouring ridges. The composition of the till on both sides of the Howells Valley is not inconsistent with this interpretation.

The principal conclusion based on the evidence collected over the past two years is that the ice-sheet in this central district melted down to reveal the ridges as nunataks, the ice thereby becoming separated into large masses occupying broad vales that lie between the ridges of the Labrador Trough. The relatively low relief of the region ensured the extreme thinness of these separated ice-masses, which were inert, any movement being purely local under the influence of gravity. The high rate of downcasting is attested by the well-developed channel forms and the wide

[1] An article dealing with this classification is in course of preparation for publication.

[2] Derbyshire, E. In Press. The recognition and classification of glacial drainage channels from aerial photographs. Geografiska Annaler.

spacing of marginal features; it is comparable with the highest figures obtained from the height of land in northern Sweden and Norway[3]. Well-developed subglacial drainage systems, evidence of marginal drainage down to present water-levels and the abundance of thick till deposits throughout the Howells Valley effectively dismiss the notion of a late-glacial lacustrine phase in favour of the occupation of the valley by a dwindling ice-mass. The neighbouring valleys, including the part of the Swampy Bay River valley investigated and the broad Knob Lake vale, also shared this history. There is no support whatever for the idea of broad, ice-dammed lakes.

The party returned to Knob Lake by bush track on September 4, one day's field work being conducted from there.

This work was undertaken with the help of a grant from the Banting Fund, administered by the Arctic Institute of North America. A detailed report will be presented to the Institute later.

E. DERBYSHIRE

Biological studies in Ungava during 1958

During the summer of 1958 the writer, with the assistance of Mr. C. W. Nicol of Cheltenham, England, was working in the False River area of Ungava, south of Ungava Bay. The principal object was as wide a study as possible of the ethology and ecology of the sea ducks (Tribe Mergini), and the False River area was chosen as a spot likely to provide nesting conditions for at least four species of this group. This was indeed the case: five species — if eiders are included — were found to breed in or near this region in 1958. However, conditions for working with these birds were extremely difficult as False River in particular proved to be an area regularly hunted over by Eskimo and part-Eskimo, who often shoot literally at everything living and within reasonable range, and are always a potential menace to the stability of local duck populations. For this reason pairs of oldsquaws that established breeding territories in the area chosen for the camp at the north end of Kohlmeister Lake moved away before egg laying began. Furthermore, the well-established eider colonies on the two small islands in False River about 5 miles north of Kohlmeister Lake suffered severe losses due to regular visits by the Eskimo for the taking of eggs of herring gulls, which also nested in large numbers on the islands, and of eggs of the eiders themselves. There was great mortality of embryos due to desertion as a result of constant interference and greater numbers of eggs were destroyed by gulls when the eiders vacated their nests quickly and failed to cover them.

As a result of this unsettled condition the area was unsuitable for the observation of normal breeding behaviour. However, as the only possible method of travel was by kayak or on foot and the tides in the river are very strong it was decided to work on other problems in the same area.

Consequently, work was started on two topics of particular interest in the region: (a) the natural mechanism of carcass disposal, and (b) the behaviour of colonial web-making spiders. Shortly after beginning work on these two projects it was found possible to work with young Mergini and so a third project was undertaken, (c) the maturation of behaviour patterns in young Mergini. Work on all three problems was continued throughout the season.

(a) *The natural mechanism of carcass disposal.*

The Subarctic with its very variable weather conditions would be expected to provide particular problems for invertebrate scavengers. To investigate these problems the inhabitants of carcasses and offal were studied, beginning in mid-June. Materials used were carcasses of muskrat, young porcupine, and eider duckling; a dish of mixed offal; two eider eggs at different stages of decay, and three pairs of tubes of solid meat and fragmented meat, placed in

[3] Mannerfelt, C. M. 1945. Nagra Glacialformologiska Formelement, etc. Geografiske Annaler, 27:1-239.

different situations. A daily record was kept of animals visiting, or living on, the material, using odour, liquefaction and disintegration as indicators, and relating these to temperature, time, and general weather conditions. None of the materials were entirely vacated by its inhabitants before we left the area on September 4.

(b) *Behaviour studies in a colony of web-making spiders.*

Subarctic weather conditions create special problems for spiders making orb-webs. In the immediate surroundings of the camp large numbers of spiders of various kinds were found and in particular a very large, diffuse colony of orb-web builders on a south-facing cliff that provided shelter from the prevailing northerly winds. A portion of this colony, containing about 40 webs, was selected for study, and for convenience divided into four sections. Records were kept of the daily changes in the state of repair and repositioning of webs in relation to insect abundance and weather conditions. Furthermore, ethological observations were made when possible, particularly with respect to web-building and reactions to prey.

During the season certain webs were selected for more detailed observation. A number of spiders from both selected webs and others have been brought back alive for further study.

(c) *The maturation of behaviour in young Mergini.*

The principal interests of the writer lie with the ethology of the Mergini. This tribe, which includes the mergansers, the golden-eye group, the old-squaw and harlequin, the scoters, and possibly the eiders, is a taxonomic assemblage of great biological interest, particularly to the behaviourist.

As mentioned above, extensive work on epigamic behaviour in this group was impossible, but enough was observed of display in common eider and red-breasted merganser to make possible a comparison with previous observations of these species at the Wildfowl Trust Collection in England. Furthermore, enough was seen of old-squaw display to suggest behavioural relationships to the above two species. As the season progressed and well-incubated eider eggs became available from the islands down-river, and broods of old-squaw moved into the camp area from which they had been scared away during the nesting period, work became possible on the maturation of behaviour patterns in ducklings. It was possible to hatch five eiders separately in camp. Four of these were imprinted to my self, but the fifth was not imprinted at all. Detailed observations were made of their behaviour, beginning with the mechanism of hatching to their reactions to predators. All normal aspects of the behaviour of the birds except display seem to be well developed within a few days of hatching.

The behaviour of my eiders was compared with that of two old-squaw broods in the area and later with that of a few wild immature eiders.

The two most important conclusions resulting from this work with ducklings appear to be: 1. there is a highly developed innate adaption to the environment, e.g. the catching of live food under water when only a few hours out of the egg, combined with 2. the necessity for a mobile guide and brooder, which normally, of course, is an adult female of the same species.

As a matter of routine, daily records were kept of birds in the area. Among the more interesting observations were the presence of a flock of approximately 500 American golden-eye for some weeks in the False River estuary; three pairs of greater black-backed gulls holding territories in the herring gull colonies on the islands in the river; redpolls nesting in the vicinity of camp; a pair of green-winged teal, which apparently bred on Kohlmeister Lake; and a flock of approximately 2,000 common and king eider broods and moulting adults in the river estuary on August 31.

It is intended to publish details of the above studies in various technical journals.

This work was made possible through a Carnegie Arctic Research Scholarship and a field grant from the Banting Fund received through the Arctic Institute of North America, which are gratefully

acknowledged. Thanks for generous assistance are also due to a number of firms, in particular to Messrs. Fry-Cadbury Ltd., C.I.L. Ltd., and Imperial Tobacco Co.

PETER M. DRIVER

Erratum, Vol. 11, No. 2

Page 121, line 6 from bottom, for Ladder-backed woodpecker, *Dendrocopos scalaris read* Northern (ladder-backed) three-toed woodpecker, *Picoides tridactylus.*

GEOGRAPHICAL NAMES IN THE CANADIAN NORTH

The Canadian Board on Geographical Names has adopted the following names and name changes for official use in the Northwest Territories and Yukon Territory. For convenience of reference the names are listed according to the maps on which they appear. The latitudes and longitudes are approximate only.

Ogden Bay, 66 NW. and 66 NE.

(Adopted January 16, 1958)			
Name confirmation			
Klutschak Peninsula	67°55′N.	98°30′W.	not Henry Peninsula
(Adopted March 6, 1958)			
Trickle River	68°00′	96°27′	
Tern Lake	67°48′	97°02′	
Red Bay	67°55′	97°12′	
Trefoil Bay	67°41′	97°08′	
Crane Peninsula	67°44′	97°06′	
Squirrel River	68°00′	96°40′	not Anderson River
(Adopted June 1, 1958)			
Weir Creek	67°48′	97°05′	not Fish-trap River nor Trap River
Shelter Creek	67°56′	98°02′	not Tent-ring River nor Ring River nor Canoe Creek

Prince Patrick Island, 99 SE. and 89 (S. ½)

(Adopted January 16, 1958)			
Name change			
Cape Beuchat	77°30′N.	113°10′W.	not Cape Beauchat

Devon East, 48 NW. and 48 NE.

(Adopted January 16, 1958)			
Name confirmation			
Cape Hardy	75°51′N.	83°50′W.	
Altered applications			
Cape Skogn	75°47′	84°15′	
Cape Sparbo	75°50′	84°02′	
Brae Bay	75°49′	83°25′	not Broe Bay
Name change			
Treuter Mountains	75°42′	82°30′	not Truter Mountains nor Trenter Mountains

Rae Strait, 57 SW. and 57 SE.

(Adopted January 16, 1958)			
Swan Lakes	68°40′N.	95°55′W.	not Porter Lakes
(Adopted October 2, 1958)			
Hill Point	69°14′	96°22′	

Somerset Island, 58 SW. and 58 SE.

(Adopted January 16, 1958)		
Altered applications		
Fury Point	72°42′N.	92°14′W.
Fury Beach	72°48′	91°54′
Cape Granite	73°43′	95°43′

Nadaleen River, 106C
(Adopted January 16, 1958)
Name change

Algae Mountain	64°34′N.	133°42′W.	not Algae Mountains

Laberge, 105E
(Adopted March 6, 1958)

Little River (locality)	61°00′N.	135°47′W.	
Porphyry Mountain	61°52′	135°59′	
Tanglefoot Mountain	61°50′	135°57′	
Green Mountain	61°50′	135°55′	
Flower Mountain	61°47′	135°58′	
Birch Mountain	61°47′	135°52′	
Mistake Mountain	61°24′	135°23′	
Surprise Mountain	61°23′	135°26′	
Black Ridge	61°22′	135°27′	
Little Braeburn Lake	61°30′	135°49′	
Little Fox Lakes	61°21′	135°40′	
Ogilvie Creek	61°23′	135°17′	
Lime Peak	61°04′	134°53′	
Mount Lokken	61°59′	134°23′	not Lokken Mountain
Mount D'Abbadie	61°42′	134°06′	not D'Abbadie Mountain
Twin Lakes	61°41′	135°57′	not Emerald Lake
The Thirty Mile (stretch)	61°30′	135°04′	not Thirtymile River
Altered application			
Claire Lake	61°53′	135°20′	
Name confirmation			
Boswell Mountain	61°11′	134°14′	not Mount Boswell

Camsell Bend, 95J
(Adopted March 6, 1958)

Carlson Creek	62°51′N.	123°53′W.	
Deceiver Creek	62°17′	123°42′	
Battlement Creek	62°11′	123°44′	
Gun Rapids	62°37′	122°10′	not Gun Rapid
(Adopted April 3, 1958)			
Name confirmation			
Ebbutt Hills	62°18′	122°10′	not Ebbutt Plateau

Nettilling Lake, 26 NW. and 26 NE.
(Adopted March 6, 1958)

Beacon Island	66°05′N.	65°57′W.	
Nunatak (settlement)	66°28′	67°03′	not Nunata (settlement)

Dubawnt Lake, 65 NW. and 65 NE.
(Adopted March 6, 1958)

Princess Mary Lake	64°00′N.	97°35′W.

Bea Lake, 85 N/10
(Adopted March 6, 1958)
Name confirmation

Treasure Lake	63°30′N.	116°36′W.

Niddery Lake, 105 O
(Adopted March 6, 1958)

Arrowhead Lake	63°37′N.	131°09′W.	
Emerald Lake	63°33′	131°13′	
Keele Lake	63°30′	130°26′	
Einarson Creek	63°45′	131°38′	
Marmot Creek	63°45′	131°18′	
Old Cabin Creek	63°42′	131°40′	
Keele Creek	63°33′	130°33′	
Emerald Creek	63°23′	131°49′	
Rogue Range	63°34′	131°15′	
Horn Peak	63°35′	131°07′	
Fault Range	63°45′	130°52′	
Marmot Pass	63°54′	131°00′	
Arrowhead Pass	63°37′	131°12′	
Selwyn Valley	63°48′	130°35′	
Name change			
Gold River	63°02′	131°43′	not Gold Creek

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